AN

ELEMENTARY COURSE

OF

CIVIL ENGINEERING.

TRANSLATED FROM THE FRENCH

OF

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FROM

THE THIRD FRENCH EDITION,

WITH

NOTES AND APPLICATIONS ADAPTED

TO

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TRANSLATOR'S PREFACE

TO THE

FIRST EDITION.

THE object of the translator in presenting this work to the public is to do something to supply what seems to him a great deficiency in the books on practical science in this country. He is acquainted with no work in English, which contains within a small compass, and in a form intelligible to common readers, those elementary principles of Engineering, which relate to building in stone, brick, or wood, and making roads, bridges, canals, and railways. Nearly all the books to be found on these subjects are suited only to the professed Engineer, and are either too voluminous, or too much involved in mathematical language to be accessible or intelligible to the greater part of learners and practical mechanics.

The work of Sganzin, of which he now offers a translation, seemed better suited than any other to the object he had in view. It has long had a high reputation in France, and has been used as a text book in the department of Civil Engineering at the Royal Polytechnic School in Paris ever since it was written. In 1823 it was adopted at the United States' Military Academy at West Point, and is still used there.

To suit it better to the wants of his countrymen, the translator has omitted such parts of the original as were applicable only to France, and, in their place, introduced facts and examples which he thought particularly adapted to the state of things in the United States. He has added notes where they seemed necessary, and has described the instruments and modes of proceeding in surveying, as practised by the United States' Topographical Engineers; the instruments made use of in France, as described in the original, being somewhat different. He has added a Chapter on the subject of Railways, compiled from the best English authorities, together with a short description of Marine Railways, and Prony's celebrated graphical method of determining the thickness of walls necessary to support embankments. He has also added some new plates and omitted some of those in the original, and has adopted a different title.

In its present form the translator hopes it will be found useful not only to the professed student of Civil Engineering, but to all persons engaged in any kind of building, in forming a road or railway or digging a canal. While so great an interest is felt, and such sums of money are expended by the nation and by individuals in public and private works, very many persons, who have no leisure or inclination to go deeply into the study, must be desirous of obtaining sufficient knowledge of these subjects to form opinions for themselves. To such persons the translator trusts he has rendered a useful service, in offering them a short work, of the best authority, capable of being understood with little study or previous knowledge of the subject.

Every person who has occasion to erect or purchase a house or other building is interested in being able to judge of the proper materials, and of the marks of skill or fidelity exhibited in its construction. Every one who is called upon to superintend or assist in building a bridge or laying out a road ought to be somewhat acquainted with the safest and most economical way of doing it. The style of building which has prevailed hitherto has been suited to an infant country. As property has become more secure, an inducement has arisen to render it more permanent. Wood is giving place to brick, as a material for building, and brick to stone, and this should be laid according to the principles of art and science gathered from many experiments. It becomes a wise nation and prudent men to profit by the experience of those who are farther advanced in the arts of life. Love of our country will lead us to build more generously, for posterity. The principles of this science should therefore be as widely spread as possible. The more numerous those are who can judge well of the materials and style of building, the less danger is there from the ignorance or craft of mechanics, and the more security that the money of the nation and of individuals will be well laid out and carry advantage to future times. Knowledge of the principles of Civil Engineering may thus be a national benefit, and he who has endeavored, however humbly, to advance this knowledge, will will not be thought to have labored in vain.

Boston, Dec. 4, 1826.

PREFACE TO THE SECOND EDITION.

In preparing a second edition of this work, the translator has endeavored to make such alterations and additions, as have been suggested by the experience of scientific gentlemen, and the improvements of the day. A most important addition will be found in the definition of all the technical terms used in the work; which are placed at the heads of the chapters in which they are used. The *Second Part*, on Roads, Canals, &c. will be found materially improved, by an alteration in the arrangement, as well as by numerous and important additions; particularly, by the introduction of Mr. Mc Adam's theory and practice of road making. The article on Harbors and their accessories has been so altered and enlarged as to be adapted to the United States and its improvements—particularly, by clear and full details upon the construction of Docks and Marine Railways, Sea Walls, &c. In fine, the whole has been so revised and improved, as to render it worthy of the patronage heretofore bestowed upon it by Schools and Academies, and subservient to the Civil Engineer, Mason, Brickmaker, Bridge builder, &c.

We particularly invite the attention of Masons to the principles herein explained for building walls, to support embankments and pressures of all kinds, as the only safe and economical mode ever pointed out.

The Translator.

Boston, August, 1828.

AUTHOR'S PREFACE.

The title of this work indicates its nature and the object proposed in laying it before the public. We do not propose to give a complete Treatise on the Art of Building or Civil Engineering; our only wish is to recall to the pupils of the Royal Polytechnic School the most important parts of an oral course, which forms a part of the course of instruction which they receive at this school.

In this course, too brief to permit us to enter into the details of the art of building, we have limited ourselves to what appeared most essential. In the first part we have treated of the various kinds of materials used in the construction of edifices; and as the exact knowledge of general principles suitable to various kinds of building is best taught by their application, we have devoted the two last parts to this purpose.

This course being delivered by an engineer of *Ponts et Chaussées*, and the circle of duties of this part of the public service offering numerous occasions to apply the principles and science which are taught at the school, it was natural to take examples from such works as are confided to this class of engineers.

There will be found in this summary, general principles, formulas, results of experience and observation relative to building, and but little designed exclusively for the pupils of this school, and it will therefore be useful not only to such students as are destined to the *Corps des Ponts et Chaussées*, but also for those destined to other branches of the public service.

This preliminary explanation is necessary in order that the object of the work and the intentions of the author may not be mistaken; besides that in laying this abstract before the public, the author has only yielded to the urgent solicitations of the *Council of Instruction* of the Royal Polytechnic School.

Paris, 1823.

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A COURSE

OF

CIVIL ENGINEERING.

INTRODUCTION.

Form of the Course. Distribution of the Parts which compose it.

THE object of this course is, to give the student as general and complete a knowledge of the subject of *Civil Engineering* as is possible in a small compass. It will be divided into thirty chapters, forming three parts. The ten first chapters will treat of materials, and will constitute the first part.

The ten following will show the applications of those substances to the construction of roads and bridges in masonry and in carpentry.

The last part, forming ten chapters, will show the principles for forming the best plan of the various kinds of canals, rail-ways, and sea-works; it will present a few applications to the navigation of rivers, as well as to canals, and seaports.

PART I.

CHAPTER I.

MATERIALS.

The consideration of materials, as the principal elements of constructions, gives rise to two kinds of inquiries.

1. The examination of their constituent parts, and their qualities.

2. Their employment.

Among materials we consider, principally, stones, brick, lime, sand, plaster, wood, and metals. Each of these kinds of material will be in succession particularly examined.

Stones.

Stones are the result of a mixture of earthy substances; simple or compound.

Naturalists, who have arranged minerals, have not all followed the same method. Some have taken as a base, the apparent or physical qualities; others have classed them according to the natural form of the aggregation of their particles. The system of the celebrated naturalist Haüy is according to this method. Again, some, at the head of whom we place Cronsted, have classed stones according to their chemical composition.

This last system being the most convenient, as well as most important in the art of building, we shall adopt it. Thus we divide stones into

$$\left.\begin{array}{l}\text{Argillaceous}\\ \text{Calcareous}\\ \text{Gypsumous}\\ \left\{\begin{array}{l}\text{Siliceous}\\ \text{Compound}\end{array}\right.\end{array}\right\}\text{Stones.}$$

First Class.—*Argillaceous Stones.*

These are composed of aluminous earth, mixed with silica and the oxide of iron. They do not effervesce with acids; they are soft to the touch, composed of laminæ, which are capable of being separated. Slate is of this class.

Second Class.—*Calcareous Stones.*

They effervesce with acids, and are in general composed of lime and carbonic acid, sometimes mixed with alumine, silica, magnesia, and the oxide of iron and manganese.

They are reduced to lime by exposure to a certain degree of heat.

In this class are included the greater part of the stones in use for constructions.* For building they are divided into two kinds, the common building stone and marbles.

Among the stones for building, marble holds the first rank for durability and the property it possesses of receiving a fine polish. Marbles for the decoration of edifices are

1. White marble, such as that of Paros and Carrara, which is used only in statuary.

2. Alabaster; this is a kind of semi-transparent marble. It is used for vases, columns, and divers kinds of interior ornaments.

3. Breccia marble, composed of angular fragments, united by a calcareous cement.

4. Pudding-stone marble, an aggregation of small round fragments united with a calcareous cement.

5. Ruin marble or Florence stone, presenting the forms of vegetables and ruined buildings.

6. Lumachella marble, an aggregation of shells, united by a cement.

Among the numerous stones of this kind, the above are the principal marbles of Italy. The principal departments of France furnish marbles similar to these several varieties; we notice in particular those which come from the Pyrenees, some of which surpass in useful qualities those of Italy, and approach in durability the ancient marbles.†

Although modern constructors seem to have reserved marbles only to be employed when polished in the decorations of edifices of a sumptuous architecture, their durability renders them proper for the construction of bridges and other works, the solidity of which constitutes their principal character. The greater part of the quarries in France are of the second class of stones; they furnish some kinds which are employed rough, or only cut, without being polished.

* The most common building stones used in the United States, are the various kinds of siliceous stones.

† Various kinds of marble, more or less valuable, are found in almost every part of the United States.—Tr.

Third Class.—*Gypsumous Stones.*

These are composed of sulphuric acid united with lime as an essential base. They do not effervesce with acids, and like the two preceding classes, do not give sparks with steel. Among the different kinds of this class, the most useful for constructions is the common gypsum or plaster of Paris.

Fourth Class.—*Siliceous and Compound Stones.*

They do not effervesce with acids ; they give sparks with steel. Those composed of fragments of stones of divers kinds united by means of a natural cement, hold the first rank in this class. We distinguish these divers kinds of stones by the name of the predominating substance, adding to it those other substances which make up the mixture. The principal ones are

Feldspar,	forming	Granite,	The common form.
Serpentine,		Serpentine,	
Petrosilex,		Porphyry,	
Arenaceous,		Sandstone,	

Among the species of the numerous genera of this class, we distinguish particularly in constructions, for their excellent qualities, granite, sandstone, lava, basalt, and puzzolana, which last, though not belonging to this class, is equally useful in the art of building; when pulverized, puzzolanas are particularly useful for constructions in water, as we shall show in the article on mortars.

Such is the general classification of stones, as adopted by engineers. Workmen consider stones in a manner more easy to observe and distinguish ; they limit themselves by classing them independently of their constituent parts, into soft and hard stones. The form or magnitude of the masses produces another division, into cut and rough stones. This division is particularly used in constructions.

We shall now examine stones proper for constructions, with respect to their durability and the magnitude of the masses.

Granite.

Granite, regarded by most naturalists as the primitive rock, is essentially composed of quartz, feldspar, and mica. Engineers and builders distinguish two kinds, the hard and the soft. The hard is that in which quartz predominates, and where there is but little mica ; it is the best for constructions. The hard granite rock, when it is of the first formation, is found in large masses or beds. If it is of the second formation, we find it in isolated blocks.

The hard granite is suitable for the construction of hydraulic works, and particularly for those which are exposed to the sea, where the force of the waves, and the sand which is thrown up upon some parts of our seacoast would soon destroy works not constructed of a very hard stone. The sea wall at *Havre* is constructed of hard granite, as high as the effect of those alluvions, called in France, *gelets*.

Many parts of the United States furnish the hard granite; Maine and Massachusetts are abundantly supplied with it. The granite from Chelmsford and Quincy, in the latter State, and that from Hallowell, in the former, have both obtained a deservedly high reputation.

The ancients frequently employed granite. The most beautiful columns and obelisks, which the Romans transported from Egypt to Rome, were of that kind of hard granite, known by the name of *Oriental granite.*

The soft granite, called in some parts of France *grison,* contains but little quartz. It is easily cut, but as it is friable, it preserves its edges but a short time, and consequently does not answer for durable works. Porphyry, serpentine, breccia, and puddingstones are never employed as cut stone for the exterior ; their scarcity renders them very precious, and this causes them to be used only for interior ornaments, such as columns, vases, and chimney pieces.

After granite, come the sandstones with respect to durability. These stones are formed of small grains of quartz more or less attenuated, and united by a siliceous or argillaceous cement. This rock is never found in continued beds, but in irregular masses, isolated, and frequently on the surface of the earth.

Sandstone.

The sandstones are divided, like the granites, into hard and soft. The hard answers for pavement stones ; that of which the texture is less close may be used as cut stone ; and that which is soft furnishes stones for grinding and polishing metals, and stones for filtering water, called *filtering jars.*

Sandstone may be employed with success either for constructions in air or water ; it resists the effects of water, and is not injured by the air ; however, it is seldom used as a rough stone, owing to its not taking mortar well.

Buhrstone, (Millstone of Cleaveland.)

Buhrstone is another siliceous stone: there are two kinds ; one is found in blocks or large masses, and is suitable for millstones in one piece ; the other occurs in single masses strewed over the country. It is formed into millstones by means of mortar and iron bands or hoops ; this second kind is also employed in masonry ; it forms permanent work, owing to the mortar lodging itself in its numerous cavities ; besides, mortar is very adhesive to it. All of the above stones resist the most violent degree of heat.

Calcareous Stones.

This class, which comes immediately after the preceding with respect to durability, furnishes the greater part of the cut stone used in France for constructions. This stone is also distinguished into hard and soft. The hard stone is that which can be wrought only with the watersaw and sandstone ; such are the marbles and some of the strata in the vicinity of Paris, called *cliquart* or freestone of a hard kind. The soft species are those which may be cut with the toothed saw. The *conflans,* the *Saint-Leu,* which are used at Paris, are of this kind.

A fine grain, homogeneous, and compact texture, uniform and equal density, the property of not absorbing water, are the properties which characterize, more or less, the goodness of these stones.

It is important for the durability of edifices to employ in their construction only such stones as possess the above characters in an eminent degree. The examination of buildings, which have been constructed with stones from a quarry which has been open a long time, will show their qualities; but if we are obliged to open a new quarry, it is necessary before using the stone to experiment upon a few blocks of it, by exposing them to air, water, to the frost, and even to fire.

We may easily discover the effect of frost upon stones which absorb humidity from the atmosphere; their surface is reduced to powder; sometimes the exterior surface falls to pieces in scales.* These species should be rejected in constructions.

If, as generally happens, the quarry presents different strata and beds, some attention is necessary in the employment of the stones, which should have the same relative position in the work which they had in the quarry, whether they are horizontal or inclined. The solidity of the work requires this precaution; intelligent workmen are seldom deceived with respect to the true direction of the strata of a quarry in a single stone, and they know very well that every stone should be placed, as they say, upon its *own bed*. A stone, which, by its situation in a mass of masonry, does not receive the pressure which it supports, in a direction perpendicular to the direction of the strata of the quarry, is, as we say, *laid against the grain*. This is an evil in constructions, which should be avoided.† Some idea of the density of stones may be obtained from their specific gravity. A knowledge of this is important, as an acquaintance with the degree of pressure, which building stones are capable of sustaining, is indispensable for success in building. A knowledge of this determines the limit in height, of a work; as that of a large arch for example.

Experiments alone can determine the absolute force or resistance of stones. Researches upon this point have

A. W. Longfellow. 1838.

* The effect of cold upon stones depends less upon the quantity of water absorbed than upon the position which it has in the stone; if in seams, it acts as a wedge; if in cavities, the pressure is equal on all sides.—Tr.

† Very little attention is paid to this particular in the United States; it is however a point which requires attention from builders in general.—Tr.

occupied engineers and skilful constructors, the results of whose experiments may be found in their works, particularly in the first volume *De l'Art de Bâtir, by Rondelet.*

In the following table of weights and resistances, we follow the order in which cut stones are considered, with respect to durability and resistance to pressure.

Extract from a Table of Resistances of Cut Stone, showing the Weights and Resistances of Stones chosen from among those kinds most generally used in Constructions of different kinds.

Species.	Weight of a Cubic Foot.	Pressure required to break a piece four inches square, (French.)
Siliceous Stones.	*Pounds.*	*Pounds.*
Basalt, . . .	201	124416
Granite from the Vosges, color of dead leaves,	186	49536
Granite, *Oriental,* . .	186	52703
Sandstone, from the environs of Pont St. Maxence,	173	56129
Calcareous Stones.		
Stone, the same quarry as that used in the construction of the bridge of St. Maxence,	175	23380
Portland stone, from Mendon,	170	29120
Freestone, from Baxneux,	170	27020

The tables of numerous experiments, from which this is extracted, prove in general, that among stones of the same class, those of the finest grain, most compact texture, and darkest color, are those which are capable of supporting the greatest weight. There is another important observation in the art of constructions, which has been proved by many experiments made upon stones of the same kind; that is, comparing their resistances, which are to each other, nearly, as the cubes of their specific gravities.* These experiments were made upon divers cubes taken from the same block of stone.

* Art de Bâtir, de Rondelet, livre V. pages 82 et suite.

By varying these experiments, and supposing several cubes, it has been discovered that a much less weight is necessary to break the mass, than if it had been composed of a single piece. Attempts have been made to determine by experiments if the power of resistance of stones increases in proportion as the area of the base increases; and what influence the form of the base has. It has been observed that with equal bases, those stones which have rectangular bases begin to break under a less weight than those with squares; and that those which have circular bases have the greatest resistance. The ratios of the resistances, in the three cases above, are represented by the following numbers: 703 for the rectangle, 806 for the square, 917 for the circle.

These last experiments give the following additional facts: cut building stone begins to give way and crack under a weight a little more than half that necessary to break it entirely. When stones are loaded with a weight less than that necessary to break them, they will, notwithstanding, crack, if this weight is permitted to act for some time.

It may be inferred from this last observation, that the props or underpinning of an edifice should never be expected to support more than half of the maximum pressure, as determined from experiments upon the stone used.

A good choice of stone, and the employment of large masses in the work, contribute much to the durability of an edifice. The monuments of Egypt, Greece, and Rome, prove, that, to obtain this double and important condition, they neither feared the expense, nor the difficulties of construction.

CHAPTER II.

CONTINUATION OF MATERIALS.

Rubble Work, Bricks, Pisé.

By the name of Rubble* we designate stones of a small size and without any regular form, which are used for filling up the interior of masonry walls.†

It is sometimes employed for the facing of walls, when beauty is not one of the essential requisites of the work.

The principal observations which have been made upon cut stone, relative to their resistance compared with their density, are applicable to stone considered as rubble. Rubble stone is generally obtained from the same quarry as cut stone. The principal good qualities of rubble are, hardness, resistance to heat and cold, and taking mortar well.

There is another kind of rubble, between cut stone proper and rough rubble; it is called picked rubble; it is squared and reduced to a uniform height; its facing is either coursed or not. Lavas, basalts, and rolled flint stone are used also as rubble in places where calcareous stones are scarce. These substances, although in general less adhesive to mortar than calcareous stone, notwithstanding, form a good filling-in.

Brick and Pisé.

Brick is a kind of artificial stone made of clay, pure or mixed. The first bricks made by the ancients were formed of clay roughly wrought, dried in the air, and hardened in the sun.

Bricks dried in the sun have been in use from the remotest antiquity; they are found in the ruins of ancient *Babylon.* Among Egyptian monuments are the remains

* In the United States we have rubble walls, coursed and uncoursed; coursed rubble is that in which the stones have been guaged and dressed with the hammer, with various degrees of finish.—Tr.

† There is another kind of filling-up, called *grubb*, or *grubbstone mortar;* this is formed by mixing small fragments of the building stone with coarse mortar, the whole forming a paste. When used, it is poured into its place between the *facing* and *the inside;* see chap. vi.—Tr.

of a pyramid which was constructed of baked bricks; the use of them was frequent in those warm climates, where they acquired great hardness. Vitruvius says, that the Greeks and Romans employed them in their edifices, and he gives the manner in which they were fabricated.

Those of the best quality were made of white or red clay mixed with sand. The best season for making them was spring or autumn, because they dry more equally at these two periods of the year. Bricks made in the summer dry upon the exterior before the interior; consequently, when the interior does dry, it must break the exterior coating. It was customary to use these bricks about two years after they were made. At present, brick baked in the sun is seldom employed, except in rural constructions, and in places where combustibles are scarce.

Pisé is a mode of construction executed with earth; this method is analogous to constructions in dried brick, but much more simple and economical. It is used with success in several parts of France, for country houses, barns, and other rural buildings; this mode of construction is particularly well adapted to Southern climates, but does not answer for the North.

The fabrication of pisé requires a fresh earth, not gravelly. Vegetable mould is generally very good for this kind of work. For making pisé the earth must be moist. The natural humidity of earth will generally give it a proper consistency for being worked; if it is too dry, it may be sprinkled with water, taking care to wet it equally, until it will adhere when pressed between the thumb and the finger.

The walls are constructed by parts, by means of a mould or *form*. The earth is thrown into this mould, formed of a frame with board sides, in layers of three or four inches in thickness; it is then beat down with a rammer made for this purpose, until the courses are reduced one half in thickness. The mould should be about 10 feet long, 3 high, and 20 inches in thickness for a common wall. When the mould is filled and the block finished, the mould is removed, and a new piece begun, taking care to give the ends an inclination of about sixty degrees, in

order to connect the blocks together; of course the joints should alternate.

The sides of the openings for the doors and windows, *socles* and *lintels*, should be made with stone or brick. Before plastering the walls, which it is customary to do, and which adds to their solidity, the work should be thoroughly dry. These details upon pisé are only the outlines of this method of building; the works of *M. Cointeraux, Teacher of Rural Architecture,* may be consulted for all the details necessary to obtain complete success in this economical mode of building.

Burnt brick is that which has acquired hardness and durability by long exposure to a violent degree of heat. The Romans employed this species of brick in the greater part of their constructions. The walls of the Pantheon of Agrippa are specimens of this mode of construction.

The Romons employed two kinds, one square, the other triangular. Triangular bricks were used for facing, and the rectangular spaces included between the two facings were filled with small stones. Modern bricks differ from those of the Romans in form and magnitude; they are rectangular, their length being double the breadth, and their thickness half of the breadth. The smallest size are from 8.28 to 9.32 inches long, and are used to construct the partition walls of chimneys; the largest are employed for the outer walls and partitions, as well as small arches, and are from 11.39 to 13.47 inches long, and from 1.41 to 1.83 inches thick.* Burnt bricks are made of the same materials as dried bricks,—clay, with more or less sand. The substances are mixed with care so as to form a ductile paste. The bricks are formed in moulds; after which they are completely dried in the shade under sheds or mats; after which they are baked or burned to a certain degree in a furnace constructed for that purpose.

Nature furnishes abundantly, argillaceous earth suitable for the manufacture of brick; if it naturally has not the necessary ductility, it may be supplied by art. The earth

* In England, burnt bricks are 9 inches long, 4½ broad, and 2¼ thick. In the United States they are different in almost every state; in the Eastern States they are 8 inches long, 4 broad, and 2 thick. In Pennsylvania they are larger.—Tr.

is mixed with divers proportions of sand or clay to bring it to the required consistency. Experience and trial determine the quantity or proportions of these mixtures. In order to facilitate the preparation of the earth and render it proper for the fabrication of brick, the clay should be dug in the month of November, and exposed to the air during the winter, and it will be fit for use the spring following. The frost and rains of winter render the earth easily worked. Particular care is required in purifying the earth from all stony and ferruginous substances with which it is frequently contaminated, because these substances serve as fluxes for melting the clay, which occasions an alteration in the form of the brick by the action of fire.

The earth should be mixed and worked with care, which adds much to the density and consequently to the goodness of the brick ; the difference of density between two bricks, one prepared after the above direction, the other in the common manner, is as 86 to 82. Of the two bricks above experimented upon, dried in the air, during the same time and under similar circumstances, and afterwards exposed to the same degree of heat, the first weighed 4 ounces more than the common brick, both having lost 5 ounces by the baking. When the same two bricks were submitted to the action of a force, which acted upon both ends while the middle was supported, the brick made with prepared clay well worked, supported a weight of 67 pounds, while the common brick supported only 37 pounds, which is equivalent to 139 pounds for the first, and 74 pounds for the second, supposing the force applied in the middle.

The resistance of bricks then is proportionate to their density. This result is analogous to what has been observed of stones of the same kind. As regards the resistance of brick to forces which tend to break them in the middle, it depends not only on care in manufacturing, but also on the quality of the material. Brick from *Maubeuge*, made with care, according to the custom of the country, when proved by experiment, have supported 470 pounds in their middle before breaking, which is more than three times the force necessary to produce fracture in the common brick, the earth of *Maubeuge* being so much superior to all other. A greater degree of perfection

may be given to brick, and their density considerably increased, by compressing the raw brick in the mould. This process, according to *M. Gallon*, author of several memoires on the fabrication of brick, is in use at *Chaumont;* it is an invention from England, where they are *struck* in moulds made of delft ware, light but very solid.* The quantity of water necessary for working the clay should depend upon the nature of the material; experiment only can determine it; in general, it should not exceed half a cubic foot for one cubic foot of clay.

Care in burning brick contributes much to the goodness of this material. This operation is performed with several combustibles,—coal, wood, and peat, each of which requires a different kind of furnace. Brick furnaces, which are heated with wood, are of two kinds, the large and small; in both, the bricks and combustible are arranged in the same manner, differing only in the quantity of bricks which they contain. The large furnaces contain 100.000, and the small ones only 25.000. In some of the northern parts of France, instead of building furnaces in a permanent manner with brick masonry, a vaulted opening only is constructed of unburnt bricks. This economical method† is also in use in Sweden. Whatever may be the construction of the furnace, the bricks are placed edgeways upon their longest side, in such a manner as to cross each other alternately. When the Swedish kiln is used a sufficient number of *fire holes* are made across the kiln which are generally from 1½ to 2 feet broad and arched, by lapping the bricks over each other, the sides should have a slight slope; and after the kiln is filled the whole should be covered with clay about four inches thick to concentrate the caloric; and in order to modify it at will, openings should be left in the sides and top.

The application of the fire requires experience. A moderate heat is commenced with and continued for 24 hours, which is afterwards increased for 36 hours. After the first 60 hours, the heat should be augmented to the greatest

* Machines for the same purpose are in common use in this country. The lateral strength of pressed brick compared with the common kind we have found to be as 411 to 194.—Tr.

† In the United States they are generally burnt in kilns, similar to the Swedish method.—Tr.

degree, and kept thus as equally as possible until the bricks are perfectly burnt. They are left to cool in the furnace.

When coal is employed, the operation is performed in the open air. The construction and filling the furnace is made at the same time. We begin by placing upon the hearth a layer of coal, which is covered with three or four layers of dried bricks, then another layer of coal; in this manner the filling is continued with alternate layers of coal and bricks, until a mound about 21 feet high, is raised.

In Holland, brick is burnt with turf. The furnaces are constructed under cover similar to the Belgic furnaces. The combustible is placed upon the hearth, which occupies the space covered by the base of the furnace.

Whatever may be the kind of furnace and species of combustible used, the entire mass of the furnace does not obtain the same degree of hardness, and there necessarily results from this, different qualities of brick in the same furnace. They are all employed in constructions, according to their durability.

Good bricks are known by a clear sound when struck, close and fine grain of the fracture, and their resistance to the action of frost. The best brick used at *Paris* comes from *Burgundy*; they have a brown red color, some are reddish yellow; both resist the heat and cold.

Well selected brick is of great use in constructions; it may be used with advantage instead of rubble, and supplies the place of cut stone where it is scarce; it may be employed in the construction of light arches; it is necessary for some species of work, such as chimneys, for furnaces and hearths where they are to support great heat. The greater part of the sluices and other hydraulic works of Holland are constructed mostly in brick masonry. This species of masonry is excellent for works in water, and when constructed with the care and precaution taken in Holland, they leave nothing to be desired either for solidity or beauty.

We will conclude this article on brick, by a few observations on *floating bricks*, which, on account of their great lightness, will float in water. It appears that the ancients were acquainted with this species of brick; they

were made in the middle ages ; it is said that the dome of St. Sophia, at Constantinople, is made of this brick. The material for fabricating this brick being rare in France, it has not been extensively used.

The celebrated naturalist *Fabroni, Director of the Florentine Museum,* endeavored to fabricate light bricks of a mineral, known by the name of agaric mineral, or fossil farina. This mineral is abundant in Tuscany ; it is composed in 100 parts of

Silica	55
Magnesia	15
Alumina	12
Lime	3
Iron	1
Water	14
	100

When this substance is ground, it produces a light powder ; it does not effervesce with acids, is infusible ; by exposure to heat, and in the furnace it loses about $\frac{7}{8}$ of its weight, without diminishing in bulk.

The bricks which Fabroni made of this substance, were specifically lighter than water, united very well with the different cements, and were not affected by heat or cold.

The mineral from which these bricks were made is friable. In order to diminish the difficulties of fabrication and to give it the necessary ductility, Fabroni mixed it with $\frac{1}{3}$ of clay. This addition of a substance heavier than water should be such, as not to deprive the bricks of the quality of floating in this liquid.

One of these bricks 7.21 inches long, 4.57 inches broad, and 1.85 inches thick, weighed only 4½ ounces, Troy. The common Tuscan brick of the same dimensions weighs nearly six pounds, Troy.

Their great lightness and infusibility at the highest temperature renders them valuable for the construction of reverberatory furnaces. They are so bad a conductor of caloric, that one end of one may be held in the hand and the other end heated red hot. This substance may be used with advantage for pyrometers, it is less expensive than Wedgwood's.

This kind of brick may be employed with great advantage for constructing kitchens on board of vessels, magazines for oil, tallow, tar, and other combustibles, in arsenals.

The late M. Faujas, Administrator and Professor in the Royal Museum of Natural History, has discovered in the department of *Ardèche* a substance similar to that of which Fabroni made his bricks, upon which he made several experiments, all of which gave the same result as the Tuscan mineral.

Desiring to test, by authentic and decisive experiment, the great utility of these bricks for masonry on board of ships, M. Faujas caused a vaulted chamber to be constructed of bricks of his own make on board an old vessel ; this was filled with gunpowder and surrounded with combustibles, then set on fire, the vessel burnt to the water's edge ; and the powder, preserved by the non-conducting power of the bricks, was not exploded. It is desirable that a discovery so valuable should be improved by our marine.

CHAPTER III.

Lime.—Modern Opinion upon this Substance.—New Experiments, made at École des Mines, by Maustier.

Lime, which may be considered the soul of masonry, is obtained by the calcination of calcareous stones.

A *natural lime* is obtained from volcanoes, but not in sufficient quantities to be generally used in the fabrication of mortars. The stone, from which lime is obtained, is a carbonate of lime more or less pure. It is known to the naturalist under the names of shell limestone, freestone, chalk, alabaster, marbles, stalactites, &c. The primitive form of this substance, when pure, is a rhomboid. Water impregnated with carbonic acid dissolves it in a slight degree ; it is not altered by exposure to air, is infusible, and when transparent and crystallized is composed of

Lime	64
Carbonic acid	33
Water	03
	100

The carbonates of lime are frequently contaminated with alumina, magnesia, silica, and the oxides of iron and manganese; frequently also with gypsum or sulphate of lime.*

Among these foreign substances found in the carbonate of lime, those which impair the quality of lime most, are alumina and magnesia. The silica combined with the limestone renders it better for mortar; the oxides of iron and particularly manganese render it what is called in the arts *maigre* or *hydraulic lime*. This species of lime gives mortar the property of hardening immediately in water. The natural combination of these oxides in the limestone produces a better mortar, than any artificial mixture.

Limestone may be calcined in an open or closed furnace, either by placing the combustible under it, or alternating in layers with the stone, according to the nature of the combustible used, which is either wood or pitcoal.

The object of the calcination is to drive off the water and carbonic acid which is combined with the lime. The water is first evaporated with a part of the acid; the remaining part of the acid cannot be expelled without the addition of a small quantity of water. Quicklime strongly attracts moisture from the air, which increases its bulk; it has the property also of strongly attracting sand, cement, and some other substances, which are used in making mortars. This mixture is made by means of water. Among the many mixtures it is remarked, that lime has a stronger affinity for silica than alumina. When water is sprinkled on quicklime it combines with it and is converted into a solid. It is owing to this, that so large a quantity of caloric is liberated. Modern chemists attribute the hardness of mortar to the solidification of water.

The hardest calcareous stones are those which furnish the best lime; at the same time all hard stones do not pro-

* The following are some of the principal tests for the composition of limestone. When it does not effervesce copiously with acids, and is hard enough to scratch glass, it contains siliceous or aluminous earth. When of a deep brown or red color, it contains oxide of iron. When it effervesces slow, producing a milky appearance, it contains magnesia; and when black and fœtid, it contains a coaly substance.—Tr.

X [illegible] and [illegible] [illegible]
[illegible]
[illegible]
[illegible] lime. [illegible] & Canals
translated by Capt [illegible] 183[illegible].
181 page.

duce the same quality of lime. From the greater part is obtained that kind called *grasse*, or common lime. It is called thus on account of its property of increasing much in bulk and forming with an equal quantity of sand, a mortar thicker than meagre lime. The species of stone, which produces hydraulic lime, is more rare than that which furnishes common lime.

Chemists, Bergmann first, have endeavored to discover by analysis the cause of the property which hydraulic lime has of forming with silica, cement, and puzzolana, a mortar, which, in a very short time, acquires a great hardness in water.

Bergmann has shown by the analysis of a stone from *Léna* in Sweden which furnishes this species of lime, that it contains manganese and a little argile. His conclusions are, that the great hardness which mortar, made with this lime, acquires in water, is owing to the natural combination of these substances; which, to form the stone of *Léna*, are in nearly the following proportions:

Lime	90
Manganese	6
Argile	4
	100

The experiments of the Swedish chemists were repeated by the late *Guyton de Morveau* with complete success; who made some new experiments upon those stones which furnish hydraulic lime. His labors upon this subject, which are particularly interesting to the scientific mason, are detailed in the *Annales de Chimie*, and in an excellent Memoir upon mortars, printed in the ninth year of the Republic. It results from the experiments of this celebrated chemist, that all calcareous stones, which produce hydraulic lime, contain manganese. × He has also detailed the process for obtaining an artificial hydraulic lime when the natural cannot be obtained, which answers equally well as the natural.* This process consists in mixing 90 parts of common limestone pulverized, 4 parts

* The principles upon which meagre or hydraulic lime acts, seem to be, that a certain quantity of water is necessary for the chemical action, which solidifies the

Genl. Treussart says, "contrary to what has been generally supposed, neither the oxide of iron, nor that of manganese, nor magnesia, can communicate to lime the property of hardening under water." (Ann. de Chim. et de Phys. 1825.

of argile, and 6 parts of the black oxide of manganese; this mixture is calcined and we obtain an excellent hydraulic lime.

An artificial hydraulic lime may be made at a less expense than that obtained by adding the oxide of manganese.

Guyton de Morveau, to whom the arts and sciences are indebted for continued researches and useful discoveries, has discovered that for this substance may be substituted the common white ferruginous oxide of manganese, which is a carbonate of lime with the oxide of manganese.

The hydraulic limestone is found in several parts of France; that from the environs of Metz produces lime of an excellent quality. Alone, without mixture with any other substance, it acquires such durability, that iron instruments are necessary to break it. The complete analysis of this stone was made during the fifth year, at this school,* and gave in 100 parts

Carbonic acid	39.
Lime	44.50
Silica	5.25
Alumina	1.25
Manganese	3.50
Oxide of iron	3.20
Water	2.25
Loss	1.05

The Senonches *(department of Eure-et-Loire)* limestone, the lime of which is much used at *Paris* for reservoirs, and in general for hydraulic works, was analyzed by the late *Descotils, Chief Engineer of Mines.* This Engineer found from his experiments, that the property which this lime has of hardening in water is owing to a large quantity of silex disseminated in small particles in the stone from which the lime is obtained; it contains one fourth of its bulk of silex, notwithstanding the analy-

water contained in the lime. Whereas in common lime, the air and its impurities are the chemical agents.

Saussure attributes it to silex and alumina in certain proportions; Descotils to silex in minute grains. It has been proved beyond a doubt, that iron and manganese are essential ingredients.—Tr.

* Imperial Polytechnick School.—Tr.

sis of the *Metz* lime, of which we have just spoken, which contains only 5.25 parts of silica in 100.*

In practice, the calcination of limestone is known to be complete by the bright conical flame that rises from the flue of the furnace without smoke, the appearance of the stone, whose color is changed to a whitish grey, and by having lost about one half of its weight; these practical indications, however, with the exception of the first, which is founded upon principle, evidently depend upon the stone, consequently are different for every different quarry. After the researches which have been made to determine the best form to be given to a lime-kiln or furnace in order to calcine the stone in the least time, and at the least expense, it has been discovered that the plan should be circular, and the profile elliptical in order to combine the best calcination with the least quantity of combustibles.†

* Such was our knowledge of lime, at the time when this "Course" was first published; but there has since appeared (1818) a work upon lime employed in building, upon rubble-stone mortar as well as common mortar, in which the author, M. Vicat, of the Ponts et Chaussés, according to the most rigorous chemical theory, and after repeated experiments, has discovered a method of converting all kinds of limestone whatever, into meagre or *hydraulic lime*. †

The operation, by which this author converts calcareous stones into hydraulic lime, is a true synthetical process, by which, with the aid of fire, the essential constituents obtained by analysis are compounded together.

As this is a very important discovery for the art of building, we shall give the author's process.

The process consists in slacking common lime under cover. We afterwards mix it with grey or brown clay, by means of a little water; from this paste we make balls which are dried and then baked to a certain degree; by this process a lime entirely different from common lime is obtained.

Being master of the proportions of this mixture, we can give to this fictitious lime any degree of energy required, and thus we may equal and even surpass the best natural hydraulic lime. The common lime will bear even 20 per cent. of argile. For the medium lime, that is, that which is a mean between the common and meagre lime, will take from 5 to 15 per cent. of argile. When we augment the quantity to 40 parts of clay to 100 of lime, the lime does not slack, the mixture is pulverant, and when moistened it becomes solid immediately, when immersed in water.

There is a particular observation made by the author; that is, if we bake clay and add it to the common lime in proper proportions (as above) we do not obtain the desired result, as when they are baked together; from whence the author concludes, that fire, which acts at the same time upon the two substances, consolidates the parts which form the mixture.

For further particulars we must refer the student to M. Vicat's work, where may be found numerous experiments in support of his theory.—AUTH.

† The following is a description of a very complete lime kiln used in England. The kiln is nearly of the shape of an egg, open a little at each end and is deep, the egg being placed on the smallest end. They should be made of fire brick inside, and when properly made are found to require less fuel in consequence of the great degree of reverberation. Near the bottom are two or more apertures; these are small at the inside of the kiln, but are sloped wide on the sides and top, as they approach the outside. These apertures are for admitting the air, and for drawing the lime. All well constructed lime-kilns should have a roof or cover; and should be furnished with an iron grating at the bottom for the ashes and small lime to pass through into the ash hole.—TR.

† A later edition [illegible]
Treatise on Calcination [illegible]
[illegible]
[illegible]

The examination and discussion of this subject is detailed in the eleventh volume of the *Journal des Mines*, p. 105.

The lime generally employed at *Paris* is not of good quality for hydraulic works; it is sufficiently good for common masonry ; the best comes from *Champigny* and is of the kind called *common.**

CHAPTER IV.

Substances which are mixed with Lime to form Mortar.—Sand—Old Mortar—Puzzolana—Basalt—Pumice—Schistose—Tress—Tournais Cinders.

Naturalists have classed sands with respect to their constituent parts, as, siliceous sand, calcareous sand, argillaceous sand, and metallic sand. In the art of building, sand is considered only with respect to the magnitude of its grains, sometimes with respect to locality ; thus, sand, whose particles are large, is called *gravel ;* sand whose parts are more attenuated and regular, is called *sand ;* that whose parts are still more tenuous, *fine sand.*

Sand is distinguished into river and pit sand. Vitruvius, and after him all Italian authors who have written on "Constructions," affirm, that pit sand mixed with lime produces the best mortar ; the moderns, among whom is Belidor, say, that river or sea sand is preferable ; the latter opinion generally prevails, notwithstanding it is in opposition to experiments made by *Rondelet.*

This skilful architect, author of the work entitled *L'Art de Bâtir*, whose zeal, in researches, for the perfection of the art of building cannot be too much commended, made many experiments in order to reconcile the diversity of opinion with respect to the best species of sand, and to determine that which merits the preference.

The following conclusions are drawn from his experiments :

* The best *common* lime obtained in the United States is that from Thomastown, Maine.

A good *hydraulic* lime has been manufactured in Madison county, N. Y. and was used for constructing the locks of the Grand Canal.—Tr.

1. That pure *siliceous sand*, mixed with an equal bulk of lime, forms mortar not so hard as sand less pure; and that this mortar requires a long time to acquire solidity.

2. That *pit sand* mixed with lime produces a mortar, better, more solid, and sooner dried, than that made with *river sand.*

3. That among all kinds of sand, that which has the darkest color produces the best mortar.

4. *Pit sand*, fresh from the pit and used immediately, produces a better mortar than that made with the same sand dried in the sun.

5. Mortar, made with fine sand, does not acquire so much hardness as that made with coarse.*

6. Powdered sandstone makes a bad mortar.

7. The powder of hard calcareous stone does not make so good a mortar, as the powder of a soft stone.

8. Lime mixed with the unburnt stone in a powdered state does not produce so good a mortar as *pit sand*, or any other powdered stone.

9. Lime from a hard stone mixed with the soft stone of *Conflans* pulverized, produced a mortar which acquired as hard and compact a consistency as the *Conflans* stone itself.

10. A mixture of lime and old mortar or cement, forms a better mortar than lime and sand.

11. Lastly, that lime mixed with glue forms a mortar which acquires more consistency and presents a more uniform texture than plaster; this mixture smoothed and rubbed with skin, becomes as brilliant as the stucco of *Italy.*

These experimental results, so important for the science of building, clearly establish Vitruvius's opinion, that pit sand and analogous substances are the best for making mortars.

Workmen at *Paris* practise agreeably to these principles, and employ pit sand for masonry, and river sand for plastering stuff.

* For hydraulic mortar, a mixture of coarse and fine sand is the best, next fine sand, lastly coarse. For common mortar, coarse sand first, mixed second, and thirdly fine sand. Great attention is necessary in the choice of sand. In nearly every city in the United States we may discover the bad effects of a want of information in this particular, as well as in some others.—Tr.

Cement, Puzzolonas, Tarras.

Cement is baked clay, reduced to powder, and generally made of broken tiles and brick.

From the constituents of bricks, which are formed of alumina and silica colored with the oxide of iron, and from the property that lime has, of forming with these substances a mixture which acquires great hardness, we might conclude, that cement has all the qualities for forming an excellent mortar.

The best cement is made of tiles and broken pottery ware, that has been well baked or burnt ; that from common bricks is rarely of a good quality, because manufacturers of this article choose the softest bricks, being more easily pulverized.

Cement made of the clay-envelopes in which Dutch or delft ware is baked, called by the workmen *coffins*, is of a superior quality. Cement made of soft bricks, may be rendered good by exposing it in a reverberatory furnace to a high heat.

The grand experiment made in the construction of the foundation of Alexander's bridge in France, leaves no doubt upon this subject. The Engineer, charged with this construction, obtained by the above means an excellent cement from bad *brick cement*. Before this operation, the cement formed a mortar that dissolved, or spread in water, consequently not proper for this species of work, for the success of which, it was necessary to use a mortar similar to puzzolana, which acquires hardness in water immediately after its employment.

Puzzolana.

Among the different substances which are mixed with lime to form mortar, the most remarkable and at the same time the most valuable, with respect to its use in hydraulic works, is puzzolana.

This substance is a volcanic production, and is found in the vicinity of active or silent volcanoes. The greater part of the country between Rome and Naples furnishes it abundantly, whence it is obtained at great expense.

Puzzolana has been found in various parts of France ; and has been made from decomposed lava in England and Ireland. This substance received its name from *Puzzoles* near Naples, from whence, according to *Vitruvius*, the Romans, who made great use of *puzzolana*, first obtained it. Naturalists have generally regarded this substance as a ferruginous clay that had been exposed to a high heat ; it occurs in the remains of porous lavas, and even in the hard ones, as basalt.

The analysis of Italian and Roman puzzolanas have generally given in 100 parts,

Alumina	40
Silica	35
Lime	5
Iron	20
	100

There are many varieties of puzzolana, of different colors, as white, black, yellow, red, brown, grey, and violet. This diversity of color is owing to the different degrees of oxidation which the iron has undergone. Its variable specific gravity is owing to the different degrees of calcination, and the proportions of its constitutent parts. All the varieties are more or less attracted by the magnet. They are generally pulverulent, being formed of powder and porous grains.

At Naples, puzzolana obtained a few feet under the surface of the earth, is preferred to that from the surface, which, having been exposed to the atmosphere, is used in works of little importance. The Roman puzzolana is of a brownish red color, lighter than that from Naples, and mixed with brilliant particles of a metallic appearance ; this puzzolana has the property of forming a good mortar without lime, which becomes hard in less than twenty-four hours. Pulverized basalt may be substituted for puzzolana after having being exposed to a certain degree of heat, to be determined by experiment ; in this state it forms with lime a good hydraulic mortar.

From experiments made at *Cherbourg* by the Engineers *des Ponts et Chaussées*, it appears that the basalt found in *Haute-Loire*, after being calcined and pulverized,

produced a mortar having all the properties belonging to those made of the best Italian puzzolana.

By analysis its composition is as follows, in 100 parts,

Alumina	16.75
Silica	44.50
Oxide of Iron	20.00
Lime	9.50
Oxide of Manganese	2.37
Soda	2.60
Water	2.00
Loss	2.28
	100.00

By comparing this analysis with that of puzzolana, it is evident they are composed of nearly the same substances, and the result obtained by making a mortar of calcined basalt might have been anticipated. Basalts are not more plenty in *France* than puzzolanas ; the expense of calcination and pulverization of basalt, renders it as expensive as puzzolana, a consideration which determines us in giving the preference to the latter.

Pumice stone may also be substituted for puzzolana ; mortar made with it has all the qualities of puzzolana mortar ; it is seldom used, however, except in the vicinity of Vesuvius.*

The Swedish engineer, M. Baggé, endeavored to find a substitute in Sweden, where there are no puzzolanas ; he found near Wenesbourg a species of very hard, black schistase, which, after analysis, appeared to answer the end proposed.

The schistase was submitted several times to a strong heat, its color was changed, it lost weight and tenacity ; after which it was easily pulverized, and made into mortar, which had all the properties of a puzzolana mortar.

Schistase being very common, this discovery may be turned to great utility in hydraulic constructions. The experiments of the Swedish Engineer have been repeated at *Cherbourg* by *M. Gratien, sen.* on several varieties of

* Trap or greenstone, when calcined and powdered, forms a good puzzolana. The Eddystone light-house was constructed with a mortar formed of lime, sand, and this species of puzzolana.

The species of mortar known in this country by the name of *Parker's cement*, is composed of calcined Septaria (a species of marl) as the principal constituent.—Tr.

schistase, and these experiments which were again repeated at Paris by a *Commission,* at the head of which was the late *Guyton-Morveau,* proved that the species of schistase used at *Cherbourg* may be substituted with advantage for puzzolana. The experimental mortars were of a good quality and took a quick set in water. There is great economy in the use of this species of puzzolana, where the stone is not distant, and wood or coal in plenty. The analysis of the *Haineville schistase* from near *Cherbourg,* gives in 100 parts

Alumina	26
Silica	46
Magnesia	8
Lime	4
Oxide of Iron	14
Water, and loss	2
	100

Tarras.

There is another volcanic substance, known by the name of *stone of Andernach,* or *brohl,* which the Dutch pulverize and sell under the name of *tarras,* from which an excellent hydraulic mortar is made.

The late *Faujas de St. Fond,* who examined this substance particularly, discovered that it was a true puzzolana.

Of the small stones, by means of their ingenious windmills, they make tarras, which is sent into the Northern kingdoms, France, and England, where this substance is favorably known.* Of *Brohl* or the largest stones, mill stones are made, which are used for various purposes. The analysis of 100 parts of tarras gives

Alumina	28
Silica	57
Carbonate of lime	6.50
Iron	8.50

* Sir H. Davy says that tarras is merely a decomposed basalt; two parts of slacked lime and one part of tarras forms the principal part of the mortar used in the construction of the Great Dykes of Holland.

Substances which will answer all the ends of puzzolana and tarras are abundant in the United States.—Tr.

Many of the Gothic churches in the Belgic provinces are constructed of tarras. By taking advantage of this circumstance, the ruins of the arches of a church demolished at Bruges, furnished at a small expense sufficient tarras for the construction of the grand sluice of Slickins. The tarras from these ruins made an excellent mortar, having all the properties of that from Holland. At Amsterdam an artificial tarras is made of clay obtained from the bottom of the sea ; it is first baked like bricks, then broken with large pestles moved by machinery, after which it is ground in mills to a proper fineness to be converted into mortar by mixture with lime.

Bergmann analyzed this artificial tarras, which has the name of *Privileged Cement of Holland*, and found it to consist, in 100 parts, of

Silica	55 to 60
Alumina	19 " 20
Lime	5 " 6
Iron	15 " 20
	94 106

Tournay Cinders.

Tournay cinders are a mixture of particles of lime with coal cinders, produced by burning a species of hydraulic lime from a very hard limestone near Tournay. This mixture forms a superior mortar for plastering the interior of cisterns, but is not abundant enough to be used for large works.

Experience has shown that coal cinders from lime kilns make a good hydraulic mortar.

CHAPTER V.

Siliceo-calcareous Stone of Boulogne-sur-Mer.—Mortars.—Slacking of Lime.—Manipulation of mixtures.—Experiments upon the specific Gravities and Force of Resistance of ancient and modern Mortars.

Siliceo-calcareous Stone of Boulogne.

This stone is a compound substance which has the property, after being calcined and pulverized, of forming an excellent mortar by itself, which readily solidifies in water.

This substance was discovered not long since on the seashore near Boulogne, and improperly called *plaster-cement.*

From the assertions of English artists who have been acquainted with this substance, it appears that it is also found in England, and abundantly in the vicinity of copper mines.

In England it is calcined and pulverized, and made an article of commerce; it is exported to India where it is extensively used. This substance, in the vicinity of Boulogne, occurs in small rolled masses, near the sea, in consequence of which this natural mortar is not extensively used, as the locality furnishes it in small quantities. It is only employed for setting joints.

A commission composed of several members of the *Agricultural Society of Boulogne* investigated and experimented upon this sigular substance; the results of which are detailed in the XII. vol. of *Journal des Mines.*

Mortars.

We designate by the name of artificial mortar, or more generally by mortar, a mixture of lime and argillaceous or siliceous substances which we have examined. This mixture should possess the property of adhering to stone and brick, and forming with it a solid mass.

There are two modes in which lime acts as a cement; in its combination with water, and in its combination with carbonic acid. When quicklime is rapidly made into a paste with water, it soon loses its softness, and the water

and lime form together a solid coherent mass, which is a *hydrate of lime.* When hydrate of lime whilst it is consolidating is mixed with red oxide of iron, alumina, or silica, the mixture becomes harder and more coherent than when lime alone is used; and it appears that this is owing to a certain degree of chemical attraction between hydrate of lime and these bodies; and they render it less liable to decompose by the action of the carbonic acid in the air, and less soluble in water.

The bases of all cements that are to be used for works which are to be covered with water must be formed from hydrate of lime.

In order that this mixture may give the above result, it is necessary that the proportions of the substances forming it should be known, either from principle or experience, but more particularly the latter. Stones and rocks are formed by nature, of earths, metals, and water combined together; the fabrication of mortar is an attempt to imitate nature in this part of her economy.

Some authors have attempted to show that the great durability of the ancient mortars is owing to the manner in which they slacked their lime; others have attributed it to their adding quicklime to the slacked, at the moment of fabrication; each, for the support of his opinion, has translated and commented upon Vitruvius in his own way, and cited as proofs his own experience in the methods advocated.

These various systems, all of which have been in vogue, have not stood the test of time. The *Loriot mortar* has lost its great celebrity; the method of slacking lime *à la Romaine* by immersion, after *M. de la Faye's* method, is now but seldom followed. Reason and experience lead us to believe that the Romans had no particular method of making their mortars. Undoubtedly they followed the same method which is now practised at Rome and throughout Italy, and it is now generally acknowledged that the great durability of the Roman mortar is not only owing to the care observed in the choice of materials, and in the manipulation, but more to the time requisite for mortars exposed to the air, to acquire the solidity and durability of which they are susceptible.

The quantities of the substances used in forming a mortar can be given only in general terms; these proportions must vary according to the quality of the ingredients.

One part and a half of common lime, which has absorbed two and a half times its weight of water, requires three parts of sand to make good mortar; the same quantity of sand requires two parts of *hydraulic lime* and a quantity of water equal in weight to the lime; these two mortars by comparison will be found to have nearly the same consistency.

This example, where two different kinds of mortar of the same consistency are obtained from the same quantity of lime, the first of which contains twice as much sand as lime, the second only one and a half, shows how little confidence can be placed in the general rules, laid down by authors upon this subject, who prescribe one part of slacked lime and two parts of sand to make good mortar. It is evident that this rule is subordinate to the quality of the ingredients of the mortar; the proportions can only be determined from experiments, which should always be made before commencing any work of importance; the relative proportions of the elements should not only vary according to their quality, but the species of mortar required. Mortar for large masses requires a coarse sand; if for constructions in water, instead of sand, argillaceous cement, puzzolana, or some similar substance is employed, and lime of the species called hydraulic, which should be employed as quicklime. Fine sand or sifted cement is necessary for laying freestone. The grout or mortar for filling up joints should be thin. Finally, plastering mortar requires the best of sand, and lime which has been slacked some time.*

The different manners of slacking lime may also have some influence upon the quality of the mortar.

Common lime is generally slacked before its fabrication into mortar; this is the custom in Italy and the greater part

* We may discover the quality of sand by the eye, and by rubbing it between the fingers; if it soils the skin by leaving earthy substances upon it, it is not good, but when clean and of a dark shining color it is generally of a good quality.—Tr.

of France. At Metz and other places where hydraulic lime is plenty, it is employed unslacked; it becomes slacked when mixed with the other component parts of the mortar. M. de la Faye, author of several *Memoires* on mortars, supposed that he had discovered the pretended secret in the fabrication of *Roman mortars* in a particular method of slacking the lime. His method is by immersion; a basket is filled with lime broken into small pieces, which is plunged into water for a moment, after which it is drained and then reduced to powder; it should be excluded from the air until used.

Rondelet, who made many experiments upon the different methods of slacking and employing lime, as well as upon the various kinds of mortar, has discovered that mortar made of lime slacked by immersion has no advantage over that made of lime slacked in the common way. He remarks that it is only by forced interpretations of a few passages of Vitruvius, that it is supposed the Romans practised this method.

It appears from Rondelet's experiments that this method does not add any thing to the lime in the way of durability, but it still appears that it possesses some great advantages over the common method followed at Paris,* since it enables us to detect such portions of the lime as are not sufficiently calcined or slacked; Rondelet gives the preference to this method, and in order to avoid the difficulties attending the immersion of large quantities, he advises that the lime be placed in the basin and the slacking finished by converting it into a paste instead of spreading it to preserve it in powder. The superiority of this method has just been established by the experiments of *M. Fleuret*, formerly Professor of Architecture in *L' Ecole Royale Militaire de Paris*, author of an excellent *Treatise* upon mortars, printed in 1807; but this author adds the indispensable precaution of making the mortar immediately after immersion, and particularly of covering it with

* According to the generally received opinion, spontaneous slacking holds the first place, slacking by immersion the second, and the common method last, for common lime. For hydraulic lime, 1. the common method of slacking, 2. immersion, 3. spontaneous. It is a point of some importance, that the purest water be used for mortars, as impure waters contain salts which have considerable influence upon the quality of the mortar.—Tr.

sand, or the other materials of which the mortar is composed, in order to prevent the escape of the vapor which exhales. M. Fleuret thinks that this vapor contains the principles for the regeneration of the lime, and consequently, that it is essential to the durability of the mortar.

Whatever may be the method of slacking, and whatever may be the species of mortar required, either of slacked or quick lime, the goodness of the mortar depends upon the intimate mixture of the substances of which it is made; it is necessary that it be made with as little water as possible, merely what is necessary for slacking the lime, when quicklime is used.

In all cases the mixture should be made with an iron hoe, and not with a shovel or stick as at Paris; the mixture should be stirred some time, and all the parts intimately blended, until no one of the *component parts* can be distinguished from the others. M. Fleuret particularly recommends that when lime is used slacked after his method, the mortar be made no faster than it is used, as it becomes hard in a short time, and in ten or twelve hours after being made, it is too hard to be worked with the trowel without moistening, which injures its quality.

Rondelet, in 1783, made several experiments with lime from *Marly* in order to discover the best proportions of materials to be mixed with this lime to form good mortar. He submitted several prisms made of the different mortars from this lime, to the action of a machine for breaking stone, eighteen months after they were made; the results obtained from these experiments are detailed in the first volume of *L'Art de Bâtir*, page 306. We shall extract the principal results in order to support the conclusions which will be drawn from them.

No.	Materials.	Quantity of Substances.	Specific Gravities.	Weight supported by a surface of 4 inches square.
1	River Sand and Lime Paste,	3—4	1.625	1866 pounds, Fr.
2	The same Mortar compressed,		1.893	2552
3	Pit Sand, Lime Paste,	3 2	1.588	2475
4	The same Mortar compressed,		1.903	3420
5	Cement of Tiles, Lime Paste,	3 2	1.457	2896
6	The same Mortar compressed,		1.663	3970
7	Cement of Tiles, Pit Sand, Lime Paste,	2 1 2	1.503	2645
8	The same compressed,		1.734	3762
9	Pulverized Silica, Lime Paste,	3 2	1.681	1783
14	Roman Puzzolana, Lime Paste,	3 2	1.320	2090
15	The same compressed,		1.442	2728
18	Naples Puzzolana, Lime Paste,	3 2	1.284	1844
19	The same compressed,		1.394	2360
32	Ancient Mortar made from Puzzolana Plaster, taken from a Roman Aqueduct,		1.549	4664
33	Ancient Mortar made from Plaster taken from an Aqueduct near Lyons,		2.028	4738
39	Mortar made from the ruins of the Bastile,		1.487	3258
43	Loriot's Mortar,		1.472	1592
44	La Faye's Mortar,		1.592	1664
46	Plaster Mortar, mixed with Lime,		1.113	3242

The following conclusions may be drawn from these experiments.

1. *Massivation*, or percussion in order to compress mortars, adds much to their durability and force of resistance to fracture.

2. Notwithstanding the prejudice in favor of river sand and pulverized sandstone, they do not form the best mortars. Pit sand, argillaceous cement, and puzzolana are preferable.

3. Cement mortar resists pressure better than puzzolana ; the Roman puzzolana is the best.

4. Loriot's mortar affords the least resistance to fracture.

5. The ancient mortars of France and Italy have nearly

the same resistance and much more than mortar only eighteen months old.

6. Mortar made of plaster and milk of lime, in eighteen months acquired a greater hardness than common mortar.

CHAPTER VI.

CONTINUATION OF MORTARS.

Plaster.

DEFINITIONS.

Force of adhesion of mortar, is the force with which it sticks to stone or brick.

Force of Cohesion, is the force with which the particles of the mortar stick together.

The increase of durability which time has given to the ancient mortars, excited the attention of Rondelet and led him to inquire into the cause of this increase ; he submitted the mortars which he had used sixteen years previous, to new experiments.

Below we have the principal results. The experiments were made upon surfaces of 4 inches square.

No.	Composition of the Mortars.	Pressure required to break them in lbs. Fr.	
		In 1787.	In 1802.
2	Mortar from Lime and River Sand compressed,	2552	2864
6	Cement Mortar, compressed,	3970	4948
7	Cement Mortar with Sand,	2645	2948
15	Roman Puzzolana Mortar, compressed,	2728	3112
18	Naples Puzzolana Mortar, compressed,	2360	3100

These experiments evidently prove that time greatly increases the durability and hardness of the mortars; since sixteen years has been sufficient to increase the force of resistance of common mortar about one eighth, that of cement mortar mixed with sand one ninth, Roman puzzolana mortar one seventh, and that of Naples puzzolana about one third. These experiments show near enough the force of resistance to fracture, of mortar itself; but in practice, it is the force with which mortar adheres to stone and brick,

which is of importance. Rondelet has examined this subject also; he found that in order to separate bricks or stone from mortar to which they had been united six months, the forces as below detailed were necessary.

No.	Details.	Force necessary for separation.
1	Two hard Freestones polished with Sandstone,	64 pounds, Fr.
2	The same, not polished,	70
3	Stones from Arcueil,	70
4	Stones from Conflans,	108
5	Millstone,	123
6	Bourgogne Bricks,	138
7	Tiles,	141
	The same experiments repeated, but using plaster instead of mortar.	
2	Freestone,	124
3	Stone from Arcueil,	127
4	Stone from Conflans,	168
5	Millstone,	189
6	Bourgogne Bricks,	201

The experiments* on common mortar and plaster show, that the softer the stone the greater the force of adhesion. The millstone is an exception which doubtless is owing to the porous nature of the stone, the mortar penetrating into the interstices.

The great adhesion of bricks and tiles is owing to the great affinity existing between lime and ferro-argillaceous substances.

It might be inferred from the above experiments that plaster is better for masonry than lime, but it should be ob-

* The following results were obtained by ourselves, from numerous experiments, on stone and brick, which had been united nine months.

No.	Details.	Force necessary for separation.
1	Two pieces of Limestone, polished with Sandstone,	71 pounds.
2	The same not polished,	79
3	Granite, hewn, from Quincy, (Mass.)	104
4	The same not hewn,	161
5	Red Sandstone, (cut)	159
6	The same not cut,	166
7	Boston unpressed Brick,	172
8	Boston pressed Brick,	167

These were united by mortar made of the best Thomastown, (Me.) lime.—Tr.

served that mortar of lime has its strength increased by time, while that of plaster decreases, particularly in humid places.

These experiments also show that the force of adhesion depends more or less upon the surfaces placed together. The force of adhesion of the mortar to the brick or stone should be distinguished from the cohesion of the particles of mortar. Although it may be difficult to determine rigorously the first force, as it depends more or less upon the polish of the surfaces, the affinity of the brick or stone for mortar and other causes, yet this force may be deduced from several experiments. It is sufficiently near to say, it is the mean of all the results; it has been found that this mean is nearly 112 pounds for a surface of four inches, or about 4000 pounds upon a square foot.

Rondelet endeavored also to measure the force of cohesion among the integral parts of mortar; he experimented upon parallelopiped masses of mortar, which had been made sixteen years, by submitting them to a longitudinal force.

The ratio of the force necessary to overcome the force of adhesion (Mortar No. 1. of the last table) to the force necessary to break a parallelopiped of the same mortar, was as 53 to 676, or as 1 to 13. With Mortar No. 6, this ratio was as 1 to 7½. With the puzzolana mortars, as 1 to 8. Nearly the same ratio was found with the ancient mortars.

When a mortar has acquired its greatest hardness, the force of adhesion of the mortar to the stones, is much greater than the force of cohesion among the integral parts of the mortar. This is invariably the case, as may be observed in the breaking of old masonry; the fracture always takes place in the middle of the joints, while the mortar cannot be separated from the stones.

The reverse is the case with plaster masonry; the force of cohesion is greater than the force of adhesion.

Béton, or Grubbstone Mortar.

Among the different kinds of mortar, this combines many advantages for constructions in water.

This mortar is generally made of hydraulic lime, sand, puzzolana, or cement, and small clippings of stone, which are added as the mortar is used.

Grubbstone mortar is used for building the foundations of hydraulic works; it is poured into the water either directly or by means of boxes made for this purpose, which prevents the mortar from spreading in passing through the fluid to arrive at the bottom. No general rule can be given for the composition of grubbstone mortar, as the quality of the materials, influences the proportions and causes them to vary. The following is the composition of a grubbstone mortar which has been employed with success:

In 40 parts,	Puzzolana from Italy	12
	Coarse Gravel	6
	Hydraulic lime (quick)	10
	Clippings of stone	12
		40

To make grubbstone mortar, a kind of basin or reservoir is made of the puzzolana, the lime is placed in this and thus slacked according to M. Fleuret, after which, the gravel is mixed with the lime and puzzolana; after the mortar is made, the stone is added, without water, that for slacking being sufficient; the mixture should be well worked with the hoe and shovel, after which it should be left for about ten hours, then again mixed before being used.

When grubbstone mortar is required to *fill up* between two walls, where it should be made massive in order to increase its density and render the work impermeable to water, the quantity of stone is reduced one half and to a smaller dimension; the gravel is also suppressed and pit sand substituted.

It is only after experiments and trials upon divers combinations of such substances as are used for mortars, by varying the proportions, and submitting the resulting mortar to immersion in water, in boxes with holes in their sides, that we are able to determine the proper proportions for a mixture which shall combine the most advantages for the various kinds of constructions.

Plaster.

This substance, known by the name of gypsum or plaster of Paris, is sulphate of lime.

This salt is insipid; it appears in many forms; its primitive form is a quadrangular rhomboidal prism; when exposed to the heat, it decrepitates and becomes friable.

Gypsum in 100 parts is composed of

Sulphuric acid	46
Lime	32
Water	22
	100

The stone which is calcined to obtain plaster is seldom pure, but is a mixture of the sulphate and the carbonate of lime.

The action of fire drives off the water of crystallization of the sulphate and the acid of the carbonate, so that calcined plaster is a mixture of quicklime and sulphate of lime deprived of its water of crystallization. From the composition of this substance it may be observed, that a certain degree of calcination is necessary to produce good plaster; too much or too little destroys the plaster. This is evidently the cause of plaster losing its hardness by exposure to the air, and why it exfoliates and falls to powder when exposed to humidity. Notwithstanding these bad qualities of plaster, which should cause it to be rejected in the construction of public edifices and monuments, this substance is very useful in the art of building and is advantageously used in particular works.

Plaster adheres strongly to stone and bricks, but slightly to wood. It is customary to stud wood with small nails which it is intended to cover with plaster, and thus both the interior and exterior of buildings in all parts where wood is used may be plastered. The best method of calcining plaster is to apply a moderate fire first in order to deprive it of that part of its water which is not chemically combined; the fire is afterwards increased, to a less degree, however, than that necessary to calcine lime; this is continued for twenty-four hours, when the calcination is completed.

Plaster is known by the workmen to be well burned, if, on mixing it with water, it has an unctuous and sticky feeling. It has not this quality when over burnt or when not burnt enough.

As calcined plaster loses its qualities by exposure to air, it is necessary to use it immediately from the furnace. It is reduced to powder. Stone or iron rollers would be very convenient for this purpose.

In places which do not furnish plaster, if it be used, the stone should be transported and not the calcined substance, and to insure the complete success of plaster it should be calcined on the spot where it is to be used.

Plaster is used in a thin or thick state according to the work for which it is intended. For pointings, a thick paste is used, and called by the workmen *hard tempered stuff;* for mouldings, a thinner stuff, called *soft tempered stuff;* for plastering, still a thinner stuff. In general, for common works it is customary to mix equal measures of water and plaster.

Plaster contains but a small quantity of carbonate of lime, consequently is not caustic, and may be handled without injury in the fashioning of the various works for which it is used, the hands being used instead of a trowel.

Plaster is sometimes mixed with lime-water, and with water containing a solution of strong glue; these give solidity, particularly the last, which may be polished. This is the Parisian mode of making stucco.

Mixed plaster has the important property of increasing in bulk by drying; while lime-mortar diminishes by becoming solid. In consequence of these properties, work constructed of plaster must be isolated from the walls; without this precaution serious injuries may result from the swelling of the plaster, even the overthrow of the walls.

CHAPTER VII.

Modern and ancient Masonry.—Method of laying Stone.

DEFINITIONS.

Appareil, is the form of the stones forming a piece of masonry.
Full mortar, is the laying of masonry with mortar upon every surface of the stones composing it.
Bond, is the laying of masonry so as to bind it together.
Laying stone upon wedges, is placing wedges of stone under a stone so as to cant it or prop it up to correspond with the work.
Cramps, are pieces of metal used for fastening stones together upon the exterior.
Coping stones, are large stones placed upon the top of a wall or like work.
Arcades, are a succession of small arches, the arches are separated from each other by pieces called *piedroits*.
Parapet of a bridge, is the wall built on each side above the roadway.

Masonry.

By this word is designated any mass of work in cut stone, rubblestone, or brick, where these species of material are cemented together by means of mortar or plaster. Consequently there are several kinds of masonry.

The first is called *Regular Masonry;* the second *Irregular Masonry.*

First Class.—*Regular Masonry.*

Many ancient monuments, owing to the regular form of the stones, were constructed without mortar, yet we call this *regular masonry*,

The object in all kinds of masonry, more particularly in this class, is to form with masses of stone united together, a single mass having the solidity of one block of stone.

The ancients were accustomed to employ in the construction of their monuments, blocks of large dimensions. In the ruins of Persepolis are found masses 55 feet long, 6½ feet in breadth, and as many deep, containing 2323 cubic feet, which would weigh over 508 tons.

In the grand temple of Balbec are found blocks still larger; in the quarry near the temple from whence these

stones were taken, blocks are found containing 10,000 cubic feet (French) weighing 2,000,000 of pounds. The boldest engineer must remain confounded when he contemplates the means necessary to move and transport such masses.

The ancients used the utmost care in dressing and fitting those surfaces which touched each other, so that the joints formed by the meeting of these surfaces could scarcely be distinguished when well laid. This perfection in the juxtaposition of their stones, has induced many to suppose that they made use of friction, by placing one stone upon another and moving them circularly.

When the blocks were not of so large dimensions as to insure their stability, they employed cramps made of iron or bronze to connect the blocks together.

The walls of the temple of Concord at Agrigentum present examples of this species of construction. The courses are formed of stones of equal dimensions in every direction cut with the greatest precision and care, and connected together by copper cramp-irons; the execution of this masonry is so perfect, that, ages after the construction of the temple, the lateral walls were pierced with arcades, cutting out the arches without regard to the joints of the stone; notwithstanding, the stones sustain each other, although several of the *piédroits* have fallen down, and with astonishment the wall is beheld perfect and entire, the innovations not having produced any disunion in the superior parts of the wall. The great duration and preservation of this monument is evidently owing to the particular care observed in its construction. The *appareil* of ancient monuments is not always so simple as that of this temple at Agrigentum. The Greeks particularly employed divers combinations in the arrangement of stones. Each of these combinations had a particular name.

Diatonoi is an arrangement of stones, whose length is double their breadth, and presented alternately in the face of the wall square and rectangular dimensions. This is called at this time the system of *headers* and *stretchers*. When the courses were all of an equal height it was called *isodomon;* two stones were necessary for the thickness of

the wall when placed as stretchers, and one when placed as headers. This system is frequently found in ancient monuments at Rome. Sometimes all the courses are not of the same height; in this case the low courses are regularly alternated with the higher; the small stones are $\frac{2}{3}$ the dimensions of the larger, in length and breadth; two of the latter and three of the former are necessary to form the thickness of the wall. This combination is the *pseudisodomon* of the Greeks. When the appareils, of which we have just spoken, do not form the thickness of the wall, and the facing only is ashlar, it is backed up with small stones called *rubblestone*. This system was called *emplecton* by the Greeks.

Another appareil of the ancients was called *opus incertum* by the Romans, and formed of stones of an irregular figure. This is the uncoursed rubble wall of the moderns. This species of construction, many specimens of which remain among ancient monuments, was particularly used for the walls of cities. This system was constructed both of large and small stones; when of the latter it was the *opus incertum* of the Romans, and comes under our second class.

Our details on the construction of ancient monuments attest the care bestowed on their construction, both for solidity and beauty. The moderns have imitated the ancients in the construction of bridges and some public monuments, but in general their examples are overlooked; the ignorance of the greater part of those who build, cupidity in contractors, and want of good faith (in many cases) on the part of the architects, have given rise and currency to a method of laying stone, expeditious and economical, it is true, but entirely vicious, that is, by means of wedges. To this method of laying stone must be attributed in a great measure the settlings and movements which have disturbed the solidity of one of the most celebrated monuments of our capitals; it is generally acknowledged that wedges and the inclination of the bed of the stone which formed the pillars of the French Pantheon (in order to obtain close and square joints) occasioned the ruin of the pillars and rendered it necessary to reconstruct them. This method has been re-

jected in works constructed by the *Ponts et Chaussées* Engineers, and in fortifications.

Workmen are induced to lay stone in this manner, because it may be done with great facility, and the work requires but little paring and trimming. By means of wedges of different dimensions a stone may be laid, notwithstanding its irregularity and other defects, so that its exterior face shall coincide with the work already constructed, and its superior bed with the general direction of the course. This facility is much increased by inclining the beds of the stone.

A stone thus laid and scaffolded upon four wedges frequently leaves between its inferior face and the preceding course an opening of an inch in thickness, which is filled with plaster or grout. In order to facilitate this operation an iron hook is used, and the openings round the stone are filled with tow or flax to prevent the liquid mortar from running out, which is removed after the mortar is dry and solid.

It is evident that the mortar, when dry, having diminished in bulk, the weight of a part of the edifice is supported by the wedges, which frequently occasions the fracture of the stones near the middle of their longitudinal dimensions, or what is still worse, the pressure causes the wall to bulge out; this generally happens when in order to produce close joints, as was the case with the Pantheon pillars, the inclination of the bed commenced one or two inches from the face of the wall.

We may diminish, in some degree, the injury incident to this method of building, by employing lead instead of wooden wedges, lead being compressible, it will permit the stone to settle in proportion as the mortar becomes hard, which will distribute the weight upon the whole surface of the bed; notwithstanding this precaution, which augments the expense of construction, this method should never be used in large works, and particularly hydraulic works. This mode may be employed without inconvenience in the construction of domes, this being a particular case, where it presents some advantages. Instead of laying stone in the manner above described, the method of *full mortar*, as it is called by the workmen, should be employed.

Before explaining this method we will say a few words upon appareil. In large works, where the thickness of the wall does not admit of the frequent use of *parpaing*, (thorough-stones,) an appareil similar to the *emplecton* of the Greeks is used; which we have already described as the system or bond of *headers* and *stretchers*. It forms a good bond with the facing and ragstone filling-in, as well as between the facing and rubble backing. *Stretchers* are those stones whose longest dimension is disposed lengthwise of the wall. *Headers*, on the contrary, are such as have their shortest dimension in the face of the wall. The stones being placed alternately, *header* and *stretcher* throughout the length of the wall, forms a course of an uniform height.

Although the size of the stone essentially depends upon the quarry, and magnitude of the edifice to be constructed, yet there should be a certain relation between the size of the headers and stretchers, to insure stability and a *maximum* of resistance, a *maximum* upon which, with equal surfaces, the figure of this surface exercises some influence.

Experience has shown that, for stone of a mean hardness, the stretchers should be three times as long as they are high, and twice the same dimension in breadth. The headers of the same dimension.

When a very hard stone is used which takes an appareil of a foot in height, the stretchers may be five times as long as high, and two or three times the height in breadth.

Economy does not admit of reducing all the stone to exactly the same height and dimensions as above given, in practice as near an approximation as possible is obtained. Whatever may be the density of the stone, the stretchers must not have too great a length, that is, never exceed six times their height; this rule is never deviated from except for coping stones for a large work. The success with which long stones were employed for the ram-part-parts of the pediment of the Louvre, and for the parapets of the bridge of Neuilly, authorizes this use, but in this case it is necessary that the beds be well worked, in order to avoid cracks which a fracture occasions.

Before placing a stone in *full mortar*, the superior bed of the inferior course is prepared and levelled, the stone is

then put in its place without mortar, and by means of the plumb, square, and level, we examine if the beds are well squared to the front of the wall if it be vertical; if an inclined wall, we examine if the bed is well dressed to the angle of inclination; the smoothness of the bed is verified, and the joints, vertical and horizontal, examined to see if they are perfect planes; finally, it is only after having discovered, by actual inspection, that the stone is cut in such a manner as to obtain a perfect juxtaposition with its contiguous surfaces, that we proceed to give it a permanent position in mortar.

If, in order to obtain a perfect juxtaposition, we should be obliged to sacrifice the cut face of a stone, it should be done, that is, if, in order to obtain a perfect joint of the inferior and superior beds, it should be necessary to carry the stone a little out from the face of the wall, it must be done; in case of this, lines are traced upon the superior surface of the stone which shall coincide with the front surface of the wall; these lines will show the front of the wall on the superior surface of the stone.

After the stone has been prepared and removed, the inferior course is cleaned and sprinkled with water and an equal layer of mortar about eight lines in thickness is spread upon it, a layer of mortar is likewise spread on the contiguous vertical face, the stone is then placed upon the mortar, by means of machinery, so as to give it its place at once, it is then shoved horizontally to make a close joint with the next stone; its position is again verified with the square and level, after which it should receive several smart blows with the hammer or mallet, until the superfluous mortar gushes out at the joints by the effect of the percussion.

It is evident that a course of masonry laid in the above manner, with no open spaces in its joints, rests upon a bed of mortar of an equal thickness throughout, and consequently, is equally compressible and will have an unalterable position and stability, as much owing to the firm position of the stone as to the adhesion of the mortar which connects the different courses together, which, according to the experiments before cited, is more than ten times the weight of the stone.

In imitation of the ancients, some modern constructors have endeavored to augment the solidity of constructions in full mortar, by making use of interior connexions, produced by inequalities in the surfaces of the beds and joints of the stone, those in the inferior course to fit and correspond with those of the superior. This method has been often tried, particularly in sea works, where the work is exposed to the force of the waves before the mortar has acquired sufficient hardness to resist so great a pressure. Experience has shown that this method does not fulfil the expectations of its friends. The precision necessary in cutting the different parts, thus augmented, which are to fit each other, can scarcely be obtained; there will always be spaces between the stones which do not touch each other, consequently, the stones will be supported by a few points of their surfaces; in fine, there always result from this method of construction, defects which, instead of consolidating the masonry, are the cause of its ruin. These defects have caused this method to be rejected by all judicious constructors, instead of which, it is recommended to use pieces of iron or copper shaped like the letter S, which are let into the stone on the superior side of the course, each stone being pierced with a hole in a vertical direction corresponding to the legs of the S through which a large bolt passes, fastening the Ss to the stones, thus connecting all the stones of a course together. In order to add still more to the solidity of this method the holes in the stones are continued through two or three courses, and the bolts thus continued, connect the courses together, so that a single stone cannot be removed without displacing two or three courses.

This method is excellent for sea works and others, which are intended to resist heavy shocks or great horizontal pressure.

In addition to the above method, cramps of iron or copper are used, which connect the blocks together.

The cramps, anchors, Ss, and bolts are sealed into the stone with lead; this is the most solid and expensive sealing; sulphur and acetite of iron may be substituted for lead, and even cement mortar, which, by oxidizing the cramps &c. in a short time will produce a very solid sealing.

Rubblestone Masonry.

This is a species of masonry constructed of large stones of an irregular shape, called *libage* by the French.

Rubble masonry is constructed of stone of a medium quality and rough as they come from the quarry, forming a masonry nearly equal to ashlar masonry in solidity, and like this latter masonry should be laid in *full mortar.* Here an abundance of mortar, as a means of connexion, is necessary, in order that the exact position of the stone may be obtained by giving it a few smart blows with the mallet, which will cause the mortar to spread in such a manner as to fill the numerous openings which the irregular form of the stone causes.

This species of masonry is employed with advantage for foundations, particularly for bridges and other hydraulic works.

CHAPTER VIII.

Rubble Stone Masonry.—Ancient.—Modern.—Brick Masonry.—Grubstone Mortar.

This class of masonry comprehends all those kinds which are made of uncut stone or brick united by means of mortar.

Ancient Masonry.

The ancients, particularly the Greeks, have left us models as well in this species of masonry as in the regular. Vitruvius has entered at some length into the details of construction for both Greek and Roman masonry, some of the principal of which we shall present to our readers. The Greeks distinguished five kinds of masonry, which include the two clases we have adopted.

The three first kinds, the *isodomon,* the *pseudisodomon* and the *emplecton* have already been described and examined in our first class, to which they belong; the next species named by Vitruvius are the *opus incertum*

and the *opus reticulatum*, which particularly belong to our second class; these will constitute the object of our researches, and we shall compare the ancient masonry with the modern.

In the *opus incertum* of the ancients, called irregular jointed masonry by the moderns, or uncoursed rubble, the facing and backing is formed of small rough stones, laid without any regard to regular courses. This species of masonry is of the remotest antiquity; it was in use at Rome in the time of the emperors, and several ruined monuments of it remain at this day. The space between the facing and backing of the *opus incertum* is filled with ragstone or chippings in full mortar, which forms a species of grubbstone mortar. This filling-up is performed by means of a box, similar to that used in making *pisé*, an improvement which renders the work expeditious; and by the solidification of the grubbstone mortar, it acquires great hardness. The angles of walls constructed in this manner should be strengthened by cutstone, horizontal courses of ashlar should be interspersed regularly throughout the wall in order to bind the stones of the *opus incertum* which naturally tend to roll; sometimes the angles are constructed of brick.

While condemning the Roman method of constructing the Grecian *emplecton*, in which were suppressed the *diatonci stones* or those which embrace the whole thickness of the wall, Vitruvius points out a defect in construction particularly applicable to the *opus incertum*, and even the *opus reticulatum*, which is, the forming the thickness of the wall of three distinct bands of masonry of different kinds, which frequently occasions settlings and crackings necessarily resulting from this heterogeneous construction.

This remark is judicious, but it is probable that the massivation remedies this fault, because cracks are not observed in such specimens as have descended to us well preserved, from the ancients.

The facing of the *opus reticulatum*, or reticular masonry, was constructed of small square stones, in such a manner as to present the figure of net work, from which it receives its name. The space between the two facings, as in the *opus incertum*, is filled up with small stone; its

angles were fortified with large cut stone, and the whole strengthened by horizontal courses of the same. The squares, which formed the facing, are placed in a chequered form; generally they are ($0^m.081$) 3.1 inches long on the sides, and between 5 and 6 inches thick, in order to form a good connexion with the filling-up.

This masonry, which presents a very pleasing combination to the eye, was much used by the Romans in the latter days of the republic, and under the emperors; it took the place of *opus incertum* which begun to become unfashionable at this time.

The vast and superb ruins of the *Villa Adriana* near Tivoli, present in all directions reticulated masonry, executed with beauty and care. Some parts of this masonry is wainscotted with marble; in the ruins of the Baths of Titus and Diocletian at Rome, are found cramps and hasps which held the marble slabs with which these reticulated walls were covered.

The Romans were acquainted with a species of rubble masonry, constructed of small stone arranged in parallel courses. An ancient ruin near the tower of Metellus, in the vicinity of Rome, was constructed in this manner; this species of masonry is similar to the Grecian *isodomon*, that is, all the courses have the same height; the stones in this masonry were about 8 inches long, the same in breadth, and about three inches in height. The modern dressed rubble masonry is an imitation of this kind of masonry. Among the various kinds of Greek and Roman appareil, the moderns have adopted only that in which the stones are arranged in parallel courses, and the *pseudisodomon* of the Greeks, that is, where it is not requisite that all the courses should have the same height; similar to the common rough walling of Paris, of which we shall soon speak.

Modern Masonry.

The first species is *dressed rubble;* it is employed in the revetement of walls, such as terrace walls, to which we wish to give a certain appearance of neatness and solidity, and should never be covered with plastering.

The good construction of this masonry requires that the stone forming the facing should be well dressed and squared, and laid in full mortar arranged in such a way as to form a system of *headers* and *stretchers*, in order to form a good connexion with the filling-up. When this masonry is well executed, it is very solid and not unpleasing to the eye. If courses of ashlar are added at the angles, forming a kind of frame, it will not disfigure a fine mass of architecture, but enrich it by forming a pleasing variety of appareil.

The second species of modern masonry is the *undressed rubble*. It differs from the first kind in this; the stones instead of being rough-hammered are employed as they come from the quarry, and laid without any regard to regular courses. The stones, however, should be well bedded. They will naturally have square faces if calcareous, or granite. When they have not they should be made so with the hammer.

In order to obtain a good *common masonry*, it is important, before placing the mortar to receive the stone, that the superior course of the wall, which is to receive the stone, should be cleaned and moistened; the moistening causes the mortar to take better; it should always be laid in full mortar. It is necessary also that all the openings caused by the roughness of the stone should be filled up with chips driven in with the hammer. Lastly, it is essential that the two facings be raised equally, and that the filling-up be kept level with the facing and backing.

If we have not always good stone from calcareous quarries, as we frequently have only volcanic products of an irregular form, and in some places only round siliceous masses which we are compelled to employ, a good masonry may be formed of these substances; if they have not the advantage of form they have the property of bedding well with mortar, and when care is bestowed in filling up all the voids resulting from the irregularities of the stone, and when they are laid in full mortar of a good quality, we generally obtain a mass of great stability. Small masonry, in general, requires great attention to ensure a firm and substantial work. The eyes of the master should never be turned from the workmen, the

work should never be parcelled out, or the workmen should never be *stinted*, on account of the deception which is generally practised on such occasions, and which it is easy to conceal. The numerous instances of the pernicious consequences of bad work should put us on our guard, and awaken the attention of the engineer, who is always responsible for the success of work confided to his care. At Paris, where plaster is abundant and of a good quality, the greater part of common masonry is constructed with it instead of lime mortar. The workmen frequently abuse the property which this substance possesses of immediately becoming hard, and, instead of dressing the stones, they place them in the work just as they come to their hands; and the coat of plaster with which they cover the wall conceals all the defects; and if walls 18 to 20 inches thick, very high, with a great number of windows, support the weight of the floors and roof, it is entirely owing to the adhesion of the plaster, a force which is considerable immediately after construction, but as it diminishes with time, edifices constructed with it cannot last long, not more than half a century, and during this time must be frequently repaired. The swelling of plaster is one cause of the rapid decay of works constructed with it; it tends to make the walls bulge out when their extremities are confined by adjacent buildings; they lose their vertical position and consequently their stability.

Our observations with respect to plaster should prevent its employment as a cement in the construction of large edifices and public monuments.

Brick Masonry.

Brick masonry is excellent for all kinds of works; the quality of being, with the exception of rubble mortar, more impermeable to water than any other species of masonry, renders it particularly suitable for hydraulic works.

The execution of this kind of masonry is more simple than that of any other, in consequence of the regularity of the masses of which it is composed. The only precaution to be observed in its construction is, to have the

bricks clean previously to being laid; it is also important that the bricks should have imbibed a sufficient quantity of water previously to being placed in their position; care is necessary in fixing their position, to have it firm, after which the bricks should be pressed into the mortar with the hand, and a few blows given it with the handle of the trowel.

Breaking joints is easily obtained in this system, since all the bricks are of the same dimensions; the combination is varied according to the thickness of the wall, and it should always be such that the bricks of one course may lap over the joints of the preceding in such a way that there shall not be a continued vertical joint; the horizontal joints should never be continued through the wall when it is more than one brick in thickness.*

There is another kind of masonry called *mixed masonry*, generally formed of courses of brick regularly alternated with courses of rubble, sometimes with flint, the face of which is the natural fracture of the stone. There are many ancient specimens of this kind of work; there are some Gothic monuments of this kind. This species of masonry, which presents nothing peculiar in its construction, is almost entirely abandoned at this time, as it requires expensive work without any advantage as to solidity.

Rubblestone Mortar.—Areas and Pavements.

Béton or Rubblestone mortar, of which we have already spoken, under the head of mortars, with which it must be classed, may be considered a kind of masonry, with respect to its use for hydraulic works. We have already given its manipulation and use, nothing more can be added respecting the details of this mixture.

The limits of our work will not permit us to dilate upon pavements and floors of edifices, which the Romans constructed of a kind of mortar, when marble was not employed, which the mortars imitated both in beauty and durability. This method is still followed in Italy, where

* There are two bonds for bricks used in the United States, one of which is placing them alternately header and stretcher; the other is laying generally, six or seven courses of stretchers, and then one course of headers.—Tr.

a factitious marble is made, the base of which is a puzzolana mortar mixed with fragments of marble, which receives a good polish. This construction is made upon the ground floor, and sometimes the higher floors of private buildings are constructed in the same manner; this method is very common in the Venetian states and at Rome. For floors it is far superior to tiles, and would be an advantageous substitute for this material.

CHAPTER IX.

Wood considered as a Material for building.

Wood is employed in the construction of edifices, either as an integral part of the building or simply as a means of construction. As an essential material, it is employed in establishing foundations for works, upon soils which do not offer a sufficient resistance; the roofs of buildings are constructed of wood; wood is also used for stair-cases and all the joiner's work with which the interior of edifices is decorated. Wood is also employed for constructing bridges and numerous other works; in fine, it is frequently used instead of masonry through motives of economy or for speedy construction.

As a secondary, wood is employed for scaffolds, centers for arches, construction-bridges, and dams; in fact it is indispensable in the art of building. Economy is highly necessary in the use of wood, which is every day becoming more scarce; the following general rules should be observed in using it:

1. Carpentry should be composed of dry wood only.
2. The pieces used should be disposed in the most advantageous manner.
3. The dimensions should depend upon the weight which the pieces are to sustain. We shall examine this material, keeping in view these three important considerations.

Among the different kinds of wood proper for the construction of edifices, oak is distinguished as combining in the greatest degree, all the qualities requisite for durability and solidity. Fir is employed with advantage in many cases; beech and elm are sometimes used instead of oak.

Botanists distinguish a great number of varieties of the oak species; for our purpose, it will suffice to examine the principal varieties which yield timber proper for the use of the carpenter.

The first variety has acorns with long peduncles. It is divided into two sub-varieties, the first produces the best timber ; its acorns are large, solitary or grouped in pairs, leaves large, wood of a yellowish white, adhesive, stiff, easy to split ; the bark close and grey.

The second sub-variety has its glands aggregated, 3, 4, and 5 together; leaf small, wood of a dark color, bark loose and open; and it is slow of growth. It is produced upon meagre, rocky soil, while the former variety grows upon good land, where the vegetable mould is deep. The wood of the first sub-variety resembles chestnut in its texture and color, which sometimes causes the latter to be taken for ancient oak; it is durable, and in general preferable to the other varieties and sub-varieties, as it furnishes more heart, less sap, and the fibres are straight and flexible.

The second sub-variety, that with small glands, gives a much heavier wood than the first; it is harder but not so straight; its fibres are frequently crossed and twisted and always cut by knots, which renders it difficult to work and liable to break when strained.

All other varieties and sub-varieties resemble more or less the two above mentioned. Carpenters make a different division, agreeing with the botanical division in the following respects,—the oak with large glands is lighter, not so hard, and is easier to work than that with small glands, which possesses the opposite qualities.

This division announces the various applications which may be made of these two varieties of wood, with respect to their qualities. The first class may be used for large carpentry, as roofs, and all the joinery and interior works. Foundations, bridges, and all other carpentry, exposed

to the inclemency of the weather may be made of the second variety; these applications, however, can only be made where the timber grows, or in sea-ports and near rivers. Frequently we are obliged by circumstances of locality to use such timber as the country affords, although the nature of the work may require other, which cannot be obtained except at a great expense.

The various kinds of pine are extensively used for constructions; the white pine is light, and very durable when kept dry; it is much easier worked than oak, and for many kinds of work is far preferable to any other wood. The hard pine is a very valuable timber, and for various kinds of scantling is very valuable, particularly in ship-building.

The names of the different parts of a tree, and the examination of its defects are necessary before proceeding to questions of resistance and employment.

The *body* of a tree is the part used for carpentry; it is composed of the bark, the sap, an assemblage of ligneous fibres called the heart, and the pith.

The *bark* is composed of several *cortical coats;* it is divided into the *liber* and *epidermis.* The *liber* is the interior part of the bark and touches the sap. The *epidermis* is the general exterior covering of the bark.

Naturalists find in the bark an admirable arrangement of organs, essential to the life of the vegetable; but considered in the respect interesting to our purposes, the bark is a soft substance, filled with cracks, and is of no use in building. The bark should be carefully removed from timber to be used for carpentry, as it adds nothing to the strength of the wood, and is injurious, since it accelerates its decay when exposed to the air. The bark is left on timber intended for piles, since their position removes the cause of decay; but if the bark is rough, it opposes a resistance to the driving of the piles, by augmenting the friction against the earth. So, under every consideration, it is best to remove the bark in every case.

The *sap* is an envelope of soft wood, which has not acquired sufficient density to become *heart*, of which it will ultimately become a part; it is imperfect wood, im-

mediately under the bark and next to the heart, with which it gradually combines.

When timber is felled in the common manner, the bark should be immediately removed; this is important, since the bark is soft and contains considerable water, and heat is generated and the bark soon decomposed; besides, worms deposite their eggs, which, in a short time after the tree is felled, are hatched and the worms attach themselves to the wood. We shall give a new method of felling wood, which is advantageous for the sap and obviates the dangers above stated.

The *heart* is that part of the ligneous fibre which constitutes the proper wood, and is formed of regular concentric cylindrical coats, from the sap to the centre of the tree where the pith is found. The pith is formed of an assemblage of longitudinal fibres crossed by transverse ones. The pith is not visible in the oak and other trees except when very young; it dries and disappears as the tree advances in age.

The different soils, climates, and exposures, occasion sensible differences in timber, independent of species and variety.

The oak, which vegetates on a wet soil, produces a soft and light wood, whose fibres are soft and weak, compared with that which grows in a dry soil. That which grows in a dry soil produces excellent timber; its fibres are full, close, flexible and strong. Timber from a thin soil, under which there is a stratum of stony earth, is generally of a good quality, but slow of growth. The two last kinds of timber have the property of bending considerably before breaking, while the soft, cracks and breaks at the moment of deflection.

Oak timber from a warm climate is generally harder and more flexible than that from a cold climate. Observation has shown that the extremes of heat and cold are not favorable to the production of good oak timber. The oak is not found in the torrid zone nor in the frigid zone. The temperature of 40 to 45 is the most favorable for the production of the hardest sub-variety; the middle and south of France and Germany, produce the beautiful sub-variety with large acorns.

Localities which are open to the north and east are the most favorable for the growth of the oak, when the soil is dry and light; but in strong and humid soils, a southern exposure is most favorable to the growth. A western exposure* is the least favorable of all, whatever may be the soil; in fact, in this situation it would be most exposed to wind and rain, which occasion accidents and diseases that affect the quality of the timber. The high or low situation of the forest modifies in some degree the quality of the wood. It has been observed that trees upon the top of a mountain, exposed to the winds, are generally crooked and stinted, while those upon the sides, being sheltered from the numerous accidents to which those on the top are exposed, are more perfect in their structure; vegetation is more rapid and abundant on the sides; and general observation establishes that timber from the sides of mountains is the best, being more straight and sound. In valleys the timber is also good, but is apt to be soft.

The situation of a tree in the forest has an influence on the quality of the wood; trees which grow upon the borders of a forest, or those in isolated and open places, acquire a much greater size than their cotemporaries in the forest; notwithstanding the beauty of the former, the latter is better timber.

The defects in timber with respect to its employment in building are ranked under the following heads,—*frosted, knotty, cross-grained, twisted, knurly, blighted, worm-eaten,* and *rotten.*

Wood is said to be *frosted*, when, by cutting it transversely, cracks are visible which radiate from the centre of the tree, sometimes called *checked;* if the cracks are numerous and large the timber is said to be *cracked;* this defect arises from the tree having been frozen, either before being felled or previously to being seasoned. Timber having this defect should be rejected for carpentry. Timber is *knotty*, in consequence of the tree having a great number of branches; this defect renders the timber unfit for joiners' work; it is difficult to work in consequence of the inequality in the hardness of the plane and

* If a western exposure is the most injurious in France, an eastern one would be least advantageous in the United States.—Tr.

knotty parts; knotty timber answers very well for hydraulic works and foundations.

Cross-grained timber is known by a certain derangement of the ligneous fibres owing to the irregular insertion of knots, which change their regularity. In working such timber, the saw cuts a great number of the fibres, which of course much diminishes the strength of the timber. Timber with this defect is rejected for interior work, but may be used for piles, as the working simply requires the pieces to be squared, or it may be employed in its natural state. *Twisted* timber is that in which the common order and direction of the fibres, longitudinal as well as transverse, is changed; this defect is similar to the last mentioned.

Rolled timber is easily distinguished by the concentric crevices between the cylindrical coats of the tree; this defect in the quality of timber, which is occasioned by violent winds while the tree is standing during the running of the sap, is much augmented by cutting and drying. Sometimes this defect is so great that the cylindrical coats may be separated from each other without any great exertion. Decay soon follows this defect, and causes timber possessing it to be rejected in constructions of all kinds; this defect is sometimes called *shakey*.

Worm-eaten timber is such as has decayed to a certain extent and then been attacked by worms; the commencement of which is indicated by the appearance of whitish spots, when the timber is said to be *foxy* by carpenters,

Wood is *carious* or *rotten*, when entirely decayed and reduced to a powder; these two last defects are without remedy, and should cause timber having indications of either to be rejected in all kinds of buildings.

Blighted wood is such as has remained standing some time after having died either of old age or disease; this defect commences at the centre, by the fibres separating; which detracts much from the strength of the wood. This defect may be discovered while the tree is standing by its top being withered, the leaves falling much sooner than from more vigorous trees in autumn, the bark being covered with moss and lichens, and other parasitical

plants. Wood *upon the return* is of no value to the carpenter.

As the durability of wood and its force of resistance are important considerations in the art of building, we shall give the different methods of felling and decortication, by which the greatest quantity of these essential qualities may be obtained.

The season proper for cutting timber in France was limited to the winter, by ancient ordinances. The experiments of Duhamel and the good results he obtained from timber cut in June and July, as respects strength, tend to prove that the summer is not less favorable than the winter for performing this operation. An observation of this Philosospher tends to prove this,—that the specific gravity of wood is nearly one sixth less in the summer than in winter a difference which he attributes to moisture.

Notwithstanding the experiments of Duhamel, the ancient custom of felling timber only in the winter generally prevails; it must be acknowledged however, that this custom has one advantage at least, that of occasioning less damage to forests than when the timber is cut in the summer.

It is essential to the preservation of timber felled in the summer to remove the bark immediately; it is necessary that it be squared shortly after being cut down; experience has shown that the sap soon undergoes changes injurious to the wood, which renders it important to employ the best means of drying and evaporating it; barking and squaring accelerates this very much. Vitruvius and other authors, who have written upon this subject, say that the density and consequently the strength of wood may be augmented, by causing the tree to die standing, either by mutilating the bark or cutting a deep gash in the trunk near the roots.

Duhamel and Buffon made many experiments to determine the best of these two methods, which were known and followed by the ancients.

These philosophers found that a deep circular cut at the foot of a tree, occasioned its death much sooner than a partial or total removal of the bark, which does not stop

the vegetation for one or two years after. Notching the tree entirely round the trunk interrupts entirely the circulation of the sap, while decortication does so only partially: it continues to flow by means of the sap wood, which it hardens in a singular manner.

The above observations should induce us to prefer the method of *barking;* which has been followed for a long time both in Germany and England, where, during the spring, while the sap runs, the bark is stripped from the tree while standing; in this situation it is left to vegetate or more properly to dry, until the following winter, at which time it is cut down.

According to the experiments of Buffon, oak 70 years of age barked in the spring, from bottom to top, suffered no change for two months, a short time after, the leaves became yellow and fell near the last of July, at which time the sap ceases to flow. One of these barked trees was cut down at this time; the wood was very heavy and hard, the sap having become as dense as the heart. The following spring the vegetation of those trees which were experimented upon and left standing, was more rapid than that of other trees of the same forest; but languished in a short time and the leaves fell in the month of August. These trees were cut down as the foliage disappeared, and the heart-wood as well as sap, which was very hard, was submitted to experiment, and compared with timber felled in the common manner, similar in age, magnitude, and other apparent qualities.

These comparative experiments were made upon pieces of equal dimensions, containing about three cubic feet.

No.	Description of the Pieces.	Weight.	Weight supported before breaking.
1	Pieces from a tree barked standing,	242 lbs. Fr.	7940 lbs.
2	Pieces from a tree not barked but felled in the common way,	234	7320
3	Pieces from a barked tree,	249	8262
4	Pieces from a tree not barked,	236	7383
5	A bar of sap-wood 3 feet long, 1 inch square, from a barked tree,	1 7⅔ oz.	287
6	A bar of heart-wood of the same dimensions from a tree not barked,	1 9⅓ oz.	256

The following conclusions may be drawn from these experiments:

1. That the absolute weight of *barked oak* exceeds that of oak not barked about $\frac{6}{100}$.

2. That the force of resistance of the *barked oak* is to that not barked as 81 to 74.

3. The sap-wood of oak barked, is not so heavy as the heart of oak not barked.

4. The force of resistance of sap-wood from a *barked tree*, is to the same force in heart-wood not deprived of its bark before being felled, in the ratio of 28 to 25.

The above conclusions are decisively in favor of decortication while the sap runs, and one year previous to being felled.

Researches as to the best disposition of the pieces composing a piece of carpentry, would be an exposition of the art itself, in which the student is supposed already to be instructed; we shall limit ourselves to recalling one general principle, that is, to arrange the pieces in triangular figures, as the angles remain constant so long as the sides do not change, a property from which results the *maximum* of strength as to the disposition of pieces, which rectangular and polygonal figures have not, the angles of which may change while the length of the sides remains constant. This important principle is daily applied in the art of carpentry.

CHAPTER X.

Resistance of Wood.—Resistance of Iron.—Experiments upon the force of Cohesion of Iron.

DEFINITIONS.

Resistance, is the power which a piece of metal, wood, or any other body, opposes to the action of a weight or power, tending to break it.

Positive resistance, is the power of a piece of wood, &c. to resist the action of a weight acting cross-ways, or laterally.

Negative resistance, is the power of a piece of wood, &c. to resist the action of a weight placed on the end of it, when it is placed upright; or it is the power to resist longitudinally.

Rupture, is the breaking of a body. The *point of rupture*, is the place where it breaks, and the *plane of rupture*, is the section of the solid where it is broken.

Inflection and curviture, of timber, &c. is the bending of it when a weight or power is applied either laterally or longitudinally.

Elasticity, is the power which a body has to return to its primitive form after the action of a weight or power upon it.

The consideration of timber with respect to its resistance when placed in the various positions forming a piece of carpentry, is one of the most important considerations in the whole art of constructions.

The history of the advancement of science in this respect cannot but be interesting, and should precede the most recent and important experiments made to determine the resistance of the different kinds of timber, preparatory to constructing works of it.

Galileo, who in the course of the seventeenth century laid the foundation of modern Physics, was the first who applied the laws of Mechanics to the resistance of solids in general. By him solid bodies were considered as composed of parallel fibres; he first sought the expression for the resistance which a solid opposed to the action of a power tending to separate the fibres longitudinally; he found that this resistance was proportional to the number of fibres. After which considering the body as submitted to the action of a force acting perpendicularly to the fibres, he easily demonstrated that the resistance, in this case, was proportional to the sum of the integral fibres

multiplied by the arm of a lever which is always a certain part of the vertical dimension of the solid in the plane of rupture.

These two principles serve as a foundation for the solution of all problems relating to the resistance of solids.

Philosophers and mathematicians, at the head of which Leibnitz must be placed, have, since Galileo, assiduously occupied themselves in researches on the resistance of solids, and among their discoveries we must not forget those of Mariotte, who, near the end of the last century, discovered that prisms firmly fixed at both extremities, would support before breaking, double the weight necessary to produce rupture if the extremities were free and unconfined. Mariotte experimented with glass rods, the contexture of which is not the same as wood, consequently his results are not applicable to timber; notwithstanding, the Academician Parent repeated the experiments of Mariotte in 1707 and 1708, and endeavored to discover if the theory of this philosopher, so useful in practice, was applicable to wood. But his experiments, made with prisms free and confined, were on too small a scale, and not made with sufficient accuracy; he found that the resistance did not follow exactly the law pointed out by Mariotte. Notwithstanding the uncertainty of Parent's experiments, he calculated from their results, employing Galileo's rule confirmed by Leibnitz, tables of resistance for timber from 6 to 36 feet in length, and from 10 to 18 inches square, French measure.

Bélidor, in 1729, instituted a new set of experiments upon the resistance of wood, and considering that the timber of carpentry is generally fixed solidly, either in a wall or at the points of support, it was a pressing motive of public utility to determine, in a more precise manner than the Academician Parent had, the law of resistance and rupture.

The experiments of Bélidor have the common fault, of having been made with pieces of small dimensions; at the same time his results, conformable in many respects to those of Parent, always agree with the law pointed out by Galileo; that is, timber resists rupture in the direct ratio of the horizontal dimensions, multiplied by the square

of the vertical dimension; and in the inverse ratio of the length.

The experiments of Bélidor also show that when both ends are confined, the piece is one third stronger than when unconfined. This conclusion, however, although agreeable to Parent's experiments, is an error.

We are indebted to Muschenbroeck for the first decisive and exact results on the resistance and rupture of confined timber. This philosopher's experiments made at Leyden, and published in 1729, show that timber in this position is capable of supporting double the weight necessary to produce fracture when not confined, and that the rupture always takes place in the middle of the piece and at the two points of support, results conformable to the first trial of Mariotte, and perfectly in accordance with the theory afterwards established by Euler.

If the last experiments of Muschenbroeck have advanced us one step towards the truth, the particular care which he observed in the choice of bodies to experiment upon, in order to remove all accidental circumstances which might influence his results, are, perhaps, so many causes to render them less useful in practice. The timber employed in building is less perfect, as its magnitude increases. It is necessary then, by experiments made upon a large scale, to obtain a kind of *formula* by which, upon the hypothesis of a less perfect material than that chosen by the Dutch philosopher, we may calculate correctly in practice the resistance of solids.

Such was the state of the science, and such the efforts of Philosophers, when by a happy combination of circumstances, Buffon combined all the means of making experiments upon a large scale, which were wanting to those who preceded him in this department of science.

This celebrated and illustrious naturalist experimented with pieces of divers dimensions from ($1^{m}.95$) 6 feet to ($9^{m}.75$) 30 feet long, and from 8 to 9 inches square; the last of his experiments forms the most interesting part of his labors. He drew up tables, in which the weight of each piece, and the weight which it supported, as well as the curvature at the moment of rupture was expressed.

This important labor, which insures to its illustrious author for ever our gratitude and thanks, is detailed in the *Mémoires de l'Académie des Sciences* of 1740 and 1741; also in the VII. vol. 12mo edition of his works. The *Encyclopédie* and several other works have been enriched by it.

In an assemblage of timber in carpentry, it is important that the pieces should preserve their primitive positions, since much of a curve would change the form of the work; consequently it is important for the solidity of constructions, to determine the ratio of the curvature to the weights which produce them; in fine, to avoid in the use of wood the limits of curvature, which sensibly change the primitive system, but more particularly that limit which immediately precedes rupture, and which is the only one noticed by Buffon.

It was in order to obtain this end, which may be called the complement of Buffon's labors, that the engineers of the *Ponts et Chaussées* employed on the maritime works of the port of Havre, under the direction of the late Lamblardie (an engineer of the first merit, whose premature death deprived the Arts and Sciences of an ardent and enlightened votary), made many experiments on a grand scale, upon the absolute *negative* resistance of wood, that is, the timber, being placed in a vertical position, was loaded with a weight which tended to crush it, in a direction parallel to the fibres.

For this purpose Lamblardie contrived a large apparatus capable of producing a pressure of 215,640 pounds, by means of which he was enabled to crush pieces 9 or 10 inches square.

The results of the first Havre experiments are detailed in the manuscript Memoires of *L'Ecole des Ponts et Chaussées*.

These experiments have been continued by M. Girard, who has perfected the machine, and conceived the happy idea of directing them in such a manner as to determine the absolute elasticity of solids.

These researches, and the curious results of his labors constitute a part of the excellent work which this engineer published in 1798 under the title of *Traité Ana-*

lytique de la Résistance des Solides, a work which contains the most complete theory anywhere to be found upon this subject.

The limit of the absolute *negative resistance* of solids (wood particularly), with respect to their employment in building is not the weight capable of crushing them, but that under which they begin to bend. So, that the object of Girard is to determine the pressure, which acting upon solids of given dimensions, parallel to the fibres, is capable of bending them.

We are induced to believe that a solid, the integral fibres of which are exactly parallel to each other, will not bend by the action of a force which acts parallel to the fibres, supposed homogeneous; it does not appear that there is any cause why the inflexion should be in one direction more than in another. But it is not thus with wood. The defect in homogeneousness between the fibres, the least difference in organization of these fibres determines the inflexion which draws them into this direction, and the whole system in consequence of the transversal adhesion follows in the same direction, the resultant acting perpendicularly to the length. In fine, in whatever manner the inflection of timber loaded at one extremity is explained, it is an experimental truth that cannot be doubted.

The experiments of Girard were made on a large scale, by the use of large pieces, some sawed and others split. He has drawn up copious tables in which all the phenomena interesting to an observer are detailed; the position of the *flèche** is shown, its greatest length when the piece is vertical or horizontal, that is, the negative or positive resistance with respect to these curvatures.† Some of these tables express the absolute elasticity of wood produced by a given weight, and the theoretical expression for the weight under which the pieces should begin to bend when loaded at one extremity.

* If a force is applied to a piece of timber it will bend and take a curved form, and the versed-sine of half this arc is the *flèche*, or it is the quantity of deflection.—Tr.

† The following are the principal formulas for the strength of timber under various circumstances when the pieces are supported at both ends.

The first tables in Girard's book relate to oak timber. The fourth table comprehends the experiments made to determine the relative resistance of deal, and its absolute resistance. Tables 8 and 9 show the absolute *mean* elasticity of a cubic metre of deal and oak, and are concluded by several miscellaneous experiments; the ratio between these two kinds of timber is shown to be a little less than 47 to 63, as has been indicated by *Perronet*.

In the same work of Girard's are found several new and interesting considerations on the strength and stress of woods, by means of which the square dimensions of scantling may be calculated for any absolute resistance, or what is much better for the stability of constructions, for the first curvature, beyond which it is not prudent to go.*

For the complete examination of such materials as enter into constructions, it remains to examine iron.

Iron.

This metal, the hardest and most elastic of all metals, is, in numerous respects, the most useful, at the same

It is known that the extension is directly as the number of parts extended, that is, as the length, and as the quantity of angular motion, which is as the length directly, and inversely as the depth. From whence we have the *flèche* or deflection, $= \frac{L^3 . W}{B . D^3}$; where $L =$ length in feet of bearing, $W =$ weight in pounds, $B =$ breadth in inches, $D =$ depth in inches.

When the beam is inclined, $D^3 = \frac{a . W . L^2 \cos c}{B}$, in which $a =$ the deflection, $c =$ the angle made with the horizon. When the beam is horizontal and fixed at one end only, $D = \left[L \sqrt{\frac{a . W}{0.6.}} \right]^{\frac{1}{2}}$, in which case $B = 0.6 \times D$. When inclined, $D = \left[L \sqrt{\frac{a . W . \cos c}{0.6}} \right]^{\frac{1}{2}}$.

Barlow on Timber.

* The following is the practical formula applicable to oak timber: $\frac{W . L^3}{72} = B . D^2 \frac{| 11.78 \times 451 | \times | L + 0.3 |}{1.3}$; and for round timber, calling d the diameter, we must substitute $(0.787 . 381)\, d^3$ for $B \times D^2$ in the last equation.—*Barlow on Timber.*

time is the most common in all parts of the world. France and Germany furnish it abundantly; there is no country in Europe furnished with it in greater abundance or of a finer quality than Sweden, whether owing to the superior quality of the mineral or the great care observed in its manufacture.

One of the distinguishing characters of iron is, that of being attracted by the magnet. Its texture, when broken, is fibrous, sometimes in grains. It crystallizes in octahedrons, one passing into the other; it is ductile, but is not very malleable.

Naturalists distinguish several species of iron, the details of which we shall not enter into, as being foreign to our purpose; we shall only examine such properties as render it useful in the art of building.

Iron expands by heat, and melts at 160° of Wedgwood, answering to 21,877 of Fahrenheit.

Its specific gravity is 7.6, which varies according to its purity. ∴ 1 cubic foot weighs 475 lbs.

The qualities of iron are modified and sometimes destroyed by different substances with which it is mixed. The most important modifications for our consideration, are the following:

Iron heated and cooled without being hammered becomes eager and brittle. Forged iron is flexible, malleable, yields to the file, and may be drawn into wire. By breaking it when cold, if it shows a fibrous texture, it is of a good quality. When forged iron is completely refined, it should not contain any foreign substance; but whatever care may be taken in this process, it can seldom be obtained perfectly pure; it will always contain a small quantity of oxygen and carbon. Iron is combustible and may be burnt in oxygen gas, by which it is deprived of all metallic properties and becomes an oxide of a varied color, from black to white, passing through red and yellow.

The various *cast irons*, and the many kinds of *forged iron* and *steel*, differ from each other only in the quantity of oxygen and carbon which they contain. Art determines the quantity necessary to produce cast iron or steel of any given quality.

Cast iron is obtained by fusing the mineral, which, by forging, is converted into *forged iron*. At the forge it is deprived of a portion of oxygen; the cast iron melts and is then hammered, by which operation it is converted into forged iron. Steel is obtained from that species of cast iron called *grey*, which contains a large quantity of carbon; if this is again combined with carbon until about $\frac{1}{333}$ part is carbon, we have what is called *German steel*. If the same operation is performed on bars of iron surrounded by powdered charcoal, in a close furnace, exposed to a great heat, the carbon, being excluded from oxygen, cannot burn, but combines with the iron, which becomes *steel of cementation*. These two kinds of steel combined, forms *cast steel*. If pieces of steel and iron are welded together, we obtain a mixed substance called *stuff*, which combines the pliability of iron with the hardness and elasticity of steel.

There are four kinds of cast iron distinguished in the arts, all having distinct properties.

1. *White cast iron*. This kind contains but a small quantity of carbon. Its fracture is silver white; it is hard and brittle, and cannot be employed for works intended to sustain shocks; it is very suitable for refining, and is easily converted into forged iron.

2. *Grey cast iron*. This kind owes its properties and the lead color of the fracture to a large quantity of carbon. It has but little ductility, owing to its containing plumbago or the carburet of iron; it has but little tenacity. The above properties render it suitable for cannon. It is not so good for refining as *white iron*.

3. *Mixed cast iron*. Its color is between the white and gray, it is used for making cannon balls, bombs, and other castings which are to afford but little resistance, as the *voussoirs* of iron bridges. This is the best species of cast iron for making forged iron.

4. *Black cast iron*. This species contains a larger quantity of carbon than either of the others. The grain of the fracture is fine, of a dark gray color; it is soft and capable of but a slight resistance, and generally is not proper for castings. The quality of cast iron may be determined by examining the forged iron, which it affords by

refining. If the forged iron is soft, tenacious and ductile, when hot and cold, the cast iron, from which it has been made, is of an excellent quality. But, on the contrary, if it is brittle when cold, the cast iron, is not good, and should not be employed for castings, particularly for large constructions.*

We also distinguish several kinds of *forged iron*.

1. *Soft iron.* It holds the first place for good qualities. It is ductile both hot and cold, owing to its great tenacity. Its fracture, in a large specimen, presents a lead color, but little strength, and not a good grain. When a small piece is broken, it appears all *nerve.* It is suitable for works of magnitude, particularly when pure and worked.

The operation of forging, singularly improves its quality, which consists in this, that instead of working the bar in its whole length, it is cut into two pieces, one doubled upon the other, and thus welded together; after which it is hammered, and cut and doubled again, and then it is shaped into such works as are wished. This operation we are frequently *obliged* to perform, in consequence of the want of bars of a sufficient magnitude for large works, which sometimes occasions a defect called *doubling*, of which we shall speak soon; it is owing to the welding not having been well performed. This inconvenience may be avoided by attention. Iron always gains, by this operation, tenacity, and other good qualities.

2. *Cold short.* This species of iron easily breaks when cold and without the assistance of the *chisel;* it is ductile when warm. The fracture in both large and small specimens, is silver white and appears to be formed of small *facets*, not showing the filiform structure. This kind of iron is harder, but not so tenacious as the *soft iron*, and is easily welded.

3. *Hot short.* The principal character of this species is that of not welding; otherwise, it has many properties in common with the first species. Workmen improperly

* The most certain test of the quality of cast iron, is to try the edge with a hammer; if the blow of a hammer makes a slight impression, denoting some degree of malleability, the iron is of a good quality, provided the texture be uniform; if fragments fly off and no sensible indentation be made, the iron is hard and brittle.

By the sound we may know if the texture be even and uniform, which will be clear for good iron, except air bubbles be present.—*Tredgold on Cast Iron.*

call it *copper iron;* it is also called *brittle iron,* by which name it is generally known.

The bad qualities of iron are generally owing to the mineral. These vices sometimes, however, result from the manner in which the ore is reduced, or the iron refined. These defects may be corrected by attention.

Among the defects of iron, resulting from its fabrication, we notice the following :

Doublings. This is in consequence of the welding not being good; its character is small gaps between the pieces composing the bar.

Cindery. This defect results from foreign matter being disseminated throughout the iron. This vice is not injurious to the hardness of the metal, but injures the appearance of the work.

Cracked iron is known by the transversal cracks, resulting from the hammering.

Flaws are small openings which extend but a short distance into the iron, occupying only the surface.

Shakes. This defect is found only in the lateral direction of the bar; it is a solution of continuity in the texture.

It now remains to show the results of experiments made to determine its tenacity, or the resistance which its cohesion opposes to rupture, by a force being applied so as to tear the metal in the direction of its length.

Muschenbroeck endeavored to find the force of cohesion of metals; but he foresaw that the good quality of his specimens would materially influence the practical utility of his labors.

He found that a bar of German iron, whose specific gravity was 7.807, which was 0.1 inch square *(Rhenish)* stretched in the direction of its length, required, in order to produce fracture, 1930 pounds *(French),* which is much beyond the mean ulterior results.

Buffon also directed his attention to this subject. The mean result of his experiments upon forged iron shows that an iron wire ($0^{m}.002$) about one line in diameter supported a weight of 495 pounds *(French)* before breaking.

The experiments of Buffon and Muschenbroeck have been repeated at the *Saint Gervais* forges with a machine similar to that employed by these philosophers, upon bars made at the *Saint Gervais* works, and from the Gun Manufactories of *Tulle* and of *Saint Etienne.*

The results, from these latter experiments are, that cast iron is not near so strong or tenacious as forged iron; a bar of cast iron about four lines square supporting only 1650 pounds *(French);* while a bar of forged iron from the same shop at *Saint Gervais*, of the same dimensions, supported 11587 pounds *(French)*, a result which shows clearly the great difference between the forces of resistance of these two kinds of iron.

The results drawn from the experiments on *Saint Gervais* forged iron, agree very nearly with those of Buffon. A bar of the *Saint Gervais* iron one line square supported 581 pounds *(French).* Buffon's experiments, cited above, upon an iron wire one line in diameter, supported 495 pounds *(French)*, which shows a little less resistance.

The *Saint Gervais* experiments on a bar of forged iron, four lines square, which supported a weight of 11587 pounds, present a result similar to the one detailed in that excellent work *L'Aide-Mémoire à l'usage des Officiers d'Artillerie;* where it is shown that a buckle of forged iron, about four lines square, supported 12000 pounds *(French).*

Tables of observations on the *Saint Gervais* experiments are inserted in the 2d Vol. of *M. Taxier de Norbec's* work, whose object is researches on Artillery.

In examining the results of these tables, we are struck with the great advantages which forged iron has over crude iron, likewise with the difference between the different kinds of forged iron, differences which show how much effect refining has upon the qualities of this metal.

Our observations show how much care and how many precautions are necessary in the manipulations for converting cast iron into forged, the homogeneousness of which evidently gives the *mamimum* of resistance, which is of some importance in works of magnitude.

Whatever may be the diversities in the results of the

numerous experiments above cited, the coincidence of many of them with those of Buffon, and with those referred to in *L'Aide-Mémoire*, clearly show, that the mean resistance of a piece of iron 4 lines square is 11 to 12 cwt. Now, as it is demonstrated, that the resistance of solids to a force acting parallel to the length of the fibres is proportional to the surface of the fracture; it is always easy to find the dimensions of a bar, which, in a certain construction, is to fulfil certain conditions.*

* Combining theory with the mean results of the numerous experiments upon iron, it has been found, 1. A bar of forged iron does not lose its elasticity so long as the weight acting, does not exceed 48 pounds per square line. 2. When a bar of iron is placed horizontally and supported at both ends, with a weight applied in the middle, the flèches of the curves produced, are proportionate to these weights when they are not large. 3. With rectangular bars of different dimensions the flèche $\propto (\text{length})^3 \propto \frac{1}{(\text{breadth} \times \text{thick})^2}$, the greatest flèche without injury to the elasticity $\propto (\text{length})^2$. A rectangular bar with the weight applied at the extremity in such a manner as to crush the bar, will resist until the weight $P = \frac{1645.\ (\text{thickness})^3}{(\text{length})^2}$. For further particulars respecting iron, the student is referred to "*Treadgold's Essay on Cast Iron*," and "*Essai sur la Resistance du Fer Forge.*"—Tr.

A COURSE

OF

CIVIL ENGINEERING.

PART II.

APPLICATIONS TO THE CONSTRUCTION OF ROADS AND BRIDGES.

CHAPTER XI.

Classification of Roads—Dimensions—Profiles of Roads in general—Paved Causeways—Gravelled Causeways.

Roads are generally divided into four classes in the United States, corresponding with their importance. To each of these classes a different breadth is given.

1st Class, about 60 feet in breadth,—National and State Roads.
2d Class, about 45 feet in breadth,—Turnpike Roads.
3d Class, about 36 feet in breadth,—County Roads.
4th Class, about 24 feet in breadth,—Town Roads.

These are the dimensions as formerly adopted both in France and England, but late improvements have shown that some of these dimensions are insufficient. In England the following division is most generally adopted.

1st Class, 70 feet broad,—Roads near the largest towns and cities.
2d Class, 60 feet broad,—Turnpike Roads.
3d Class, 48 feet broad,—County Roads.
4th Class, 30 feet broad,—Parish or cross Roads.

The breadth of all roads should be proportioned to the traffic to be employed upon them.

Roads of the first class, are such as lead from the capitals of states, or from large cities, and communicate without interruption with the principal cities of the same state or with neighboring states.

The second class, are such roads as are constructed by companies incorporated for the purpose, and generally lead from one city to another of the same state.

The third class are such roads as are constructed by the counties through which they pass; and generally lead from the principal town of one county to that of another.

The fourth class, are such roads as lead from the three former classes, to the different parts of a town or county.

There are different orders of roads in the same class.

Economy in the excavation of roads situated in mountainous countries, together with other local circumstances, frequently cause a diminution to be made in the breadth of the two first classes; which necessarily causes the sub-division of a class into orders.

The constituent parts a road are, a solid causeway or metalled part, in the middle;* a wing in earth on each side of this, and sometimes a foot-path in addition; then the slopes to the excavation or embankment (as the case may be), which supports the wings; lastly, ditches for conveying off the water. When local circumstances cause a diminution in the breadth of a road, it is to be made from the wings and ditches only, the breadth of the causeway or road proper, should never be less than eighteen feet.

The causeway is either paved or covered with small stones and gravel. This part of the road being the carriage way, requires great solidity. The wings are constructed of earth, and are intended particularly for foot passengers. In fine seasons they afford an easy and sufficiently solid carriage way; and thus preserve the causeway. The wings are sustained by the slopes of the embankment when the road is upon level ground or by the slopes of the ditches when the road is excavated, that is, when the superior surface of the road is below the natural surface of the ground.

* Sometimes they may be more commodiously placed on the sides, and the earthen part in the middle.—Tr.

The superior surface of the causeway generally should present a convex surface, of a greater or less curvature, according to the kind of road required. The object of this curvature is to facilitate the draining off of the water, from both sides. This essential condition obliges us to keep the surface of the road above the natural surface of the ground; but when this cannot be obtained, which is the most economical, the necessary relief is given to the road for carrying off the water, by means of two ditches.

This condition for draining the water, requires the wings to be inclined towards the crest of the slope of the embankment, or towards the ditch; this inclination is determined by the nature of the ground, and particularly by the longitudinal slope of the road, which should always be less than the transversal slope of the wings, in order that the water may not be induced to run along the road.

In some cases the causeway may occupy the whole breadth of the road; a solid and deep soil, and a great abundance of gravel authorizes this variation. Some of our southern departments and England furnish examples of this mode. Such, in a few words, is the transversal profile of a road, to which we shall return in a short time, after having treated more particularly of its construction.

The accessory and ornamental works to a road consist of plantations, mile-stones, and guide-boards; fountains and watering places are also placed at certain intervals along the road.

Among these works, plantations of trees hold the first rank.* They embellish the road, serve to shade the traveller in summer, and direct him in such places as are liable to inundation or to be covered with snow.

The trees are generally planted without the ditches,

* Plantations of trees should never be made close to roads, and the distance at which they should be placed, must depend on the elevation of the country, the soil, &c. on the breadth of the road, its direction, whether the plantation is to be placed on the north or south side of the road, its thickness, and kind of tree, &c. A broad and winding road, has chances of the direct influence of the sun and wind, according to the obliquity of its angles. A road running north and south will have the sun a part of every day in the year, though closely planted on each side; one running east and west, planted on the south side, with trees forty feet high, will have no sun during the three winter months. Supposing the average height of the sun during these months to be 20°, then a tree 40 feet high will throw a shadow every day during that period, upwards of 100 feet long, which may show that no plantation should be nearer the south sides of roads than 80 or 100 feet. On the north, east and west sides, they may be nearer, according to the elevation, &c. —Tr.

but it is generally conceded now, that it is more advantageous, particularly for roads of the first class, to place them upon the exterior edges of the wings with the precautions necessary for their preservation; they grow much better when placed there, because the plough is liable to injure them when placed beyond the ditch; the latter position produces a finer appearance and affords a better shade to the traveller.

Such species of trees should be chosen for this purpose as are suitable to the soil and produce an useful timber, as the oak, the elm, and the ash; fruit trees should never be used for this purpose, their produce exposes them to depredations and injuries. Way-stones in France were formerly placed 1000 toises from each other; according to the new system of measures these are to be replaced by *kilométrique* boundaries. Every tenth one is to be a large stone, and will indicate a *myriamètre*, a denomination adopted as the unit of measure for roads; it is a space of about two French leagues and a half, or 2000 toises.* These stones are very convenient for pointing out the divisions for keeping the roads in repair, they also show the traveller how much he has travelled and how much he has yet to travel. Guide-boards are not less useful, and should be placed at every corner on the road; they quiet the uncertainty of the traveller, and prevent his losing the way.

To these useful accessories must be added, when locality will permit, fountains and other watering places; these works should be placed on the side of the road.

These monuments show the solicitude of the government for the comfort of the people. The Romans have left us noble and magnificent examples to follow in this respect, and we should endeavor to imitate them by giving to our roads not only the solidity necessary for the purpose intended, but also the embellishments and conveniences which public utility demands.

After having given the various *parts* of a road, we shall now give the details for their construction, which must be known before we speak of the manner of projecting them, together with a few definitions of terms used in the construction of roads.

* In this country it is customary to place stones at every mile.—Tr.

By *slope* or *ramp* we understand the inclination of a line above or below the horizon; thus, slope indicates descent, and ramp, ascent. But in order to avoid all ambiguity in this respect, it has been agreed to designate slopes and ramps according to their direction. The tangent of the angle of inclination to a radius of unity, is the measure of the ramp or slope, both of which are called total or absolute when this tangent is referred to a radius greater than unity.

Deblai or *excavation*, is the result of the operation by which such parts of the natural soil as are above the level of the road, are removed.

Remblai or *embankment*, is the result of the operation by which a certain relief is given to the natural soil, necessary to raise it up to the level.

The transversal profile of a road is a discontinued figure, which gives the position and magnitude of the causeway, as well as of every other part of the road.

In order to trace the profile of a road; (*Plate* 1, *Fig.* 1.) upon a line equal to the total breadth of the road we form an isosceles triangle, the perpendicular of which is to the base, as the absolute slope, is to the breadth of the road; in common cases this relation is $\frac{1}{24}$ of the breadth of the road. We then project upon the sides, the causeway measured upon the base of the triangle; through these three points we draw an arc of a circle, which shows the convexity of the road, what remains of the two sides of the triangle forms the wings. To complete this profile only requires the addition of the slopes to each side of the figure, if the road is elevated above the natural soil, or in *embankment;* or the slopes of the ditches, if the road is in *deblai* or excavation.

But in order to complete the detail, the thickness of the causeway and kind of construction should be given. The solid which composes this does not depend upon the excavation or embankment; it is entirely an artificial work, having a distinct structure independent of the removal of earth.

The middle or causeway part of a road is constructed in two ways; it is either paved or gravelled, or sometimes it is in stone.

Paved Causeways.

Granite, whinstone or trap are preferred for paving, water-worn granite or trapstones are sometimes used for this species of construction; and in order to give sufficient stability to the work, the stones should be cubes, and measure about eight inches on each side, and should be placed upon a firm bed of sand, which is called the *form*, of about six inches in thickness; the stones should be placed normally to the curve of the profile, in rows in such a manner as to break joints. The two exterior rows are called *curb stones* or *borderers;* their length and depth should be greater than that of the other stones, in order that they may consolidate and keep the stones in their position by sinking deep into the *form,* and form an interior and alternate connexion with the pavement stones. After the stones are placed with the precaution that their superior surfaces satisfy the profile, each stone should receive a few sharp strokes from the paving-beetle to give it a firm position, after which a layer of sand should be spread over the whole, about an inch thick; this is necessary in order to fill up the openings in the joints.

In the profile of a causeway formed of an arc of a circle, the curb stone, on account of its position, has the greatest slope, consequently, if the wheels of carriages come upon this part of the road they will slide to the wing and form a rut. This inconvenience is but imperfectly remedied by giving a saliency, at certain intervals, to the curb stones by carrying them out on the wings, but on the contrary this frequently is the cause of new injury. An *épaulement* or course of small flinty stones in such cases, is far preferable; they are placed on the wings against the *borderers*, as indicated in the profile *(Figs.* 2 *and* 3).

In order to preserve the wings of roads entire when the causeway is paved, the above profile should be renounced for the profile *à revers* or a reversed profile, of which we shall speak after having terminated our details upon the construction of causeways. This profile has the property of causing the wheels of carriages to return to the causeway after having left it. Paved causeways are generally

made in the environrons of cities, also on such roads as cross cities and villages.

Stone and Gravelled Causeways.

These are the kinds of causeways most extensively used (*Fig.* 4 *and* 5, *Plate* 1). They are formed of several layers of stone ; most frequently this number is three; they are formed of the chips of stone, the hardest, particularly if siliceous, are reserved for the superior course. The first layer may be regarded as the foundation, and when the *form* is horizontal, should be about nine inches thick, formed of small rough stones ; the fragments of cut stone are very good, and should be placed edgeways, without regularity, only being careful not to leave open spaces; such points of the stones as are elevated above the rest will serve to connect the strata together.

The first stratum thus prepared is covered by a second, which should be about three inches thick ; stones collected upon the surface of the earth are employed for this purpose, flint when it can be had; whatever kind of stones is used, they should be reduced to a uniform size, so as to weigh about 6 oz.; this second stratum is arranged upon the first by means of a hoe, and should present a uniform surface corresponding to the profile adopted.

The third stratum* should be about three inches thick, of coarse gravel or hard siliceous stones, broken fine and with care, in order to have them all of the same size, and a little smaller than those for the second layer; these should be arranged upon the second stratum with a rake.

These three strata, which constitute the causeway, are retained in their positions by two rows of curb stones, but instead of their superior surfaces being on a level with the road as in the paved causeway, they should be covered by the stone or gravel of the upper stratum; when the causeway is finished the edges of the borderers should be the only parts visible; this edging is either a right line or curve, parallel to the axis of the road, and separates the causeway from the wings of the road.

* According to Mr. Strickland, the best roads in England have but two strata, the first being paved with rubble stone seven or eight inches thick, the second gravel and small stones well rammed, four inches thick.—Tr.

This position of the borderers (as shown by *Fig.* 5, *Plate* 1), presents many advantages. They confine the second and third layers, with which they are connected, and, by their elevation above the wings, protect these against the wheels of carriages which are liable to injure them in this part.

By analyzing the properties and results of this species of construction, it is evident that it presents all the requisites for solidity when made with care, and when the materials, particularly those for the two last layers, are well chosen. In fine, the small stones or gravel of the third course arrange and mix with the second, by the effect of the carriage wheels and travelling; the fragments which wear off mix by means of water and form a cement, which augments the points of contact and by degrees fills up all the crevices; after a certain time there results from this, a homogeneous mass, hard and compact on the surface, which entirely resists the friction of travelling, even of heavy carriages.

When the ground is of a bad quality for the solidity of roads, the first layer should be placed upon a foundation of flat stones about six inches thick.

The success of this species of causeway depends essentially upon the constructors, and particularly upon the care bestowed in placing the third stratum. Constant care and continued observation to fill up the ruts as fast as they are formed, are the indispensable means of preserving a causeway of this kind.

McAdam's Theory and Practice of Road Making.

McAdam's theory of road making may be comprised in the following words. Roads can never be rendered perfectly secure until the following principles be fully understood, admitted, and acted upon: namely, that it is the native soil which really supports the weight of traffic; that while it is preserved in a dry state it will carry any weight without sinking, and that it does, in fact, carry the road and carriages also; that this native soil must previously be made quite dry, and a covering impenetrable to rain, must then be placed over it to preserve it in that dry state; that

the thickness of a road should only be regulated by the quantity of material necessary to form such impervious covering, and never by any reference to its own power of carrying weight.

Roads placed upon a hard bottom, it has been found wear away more quickly than those placed upon a soft soil. It is a known fact, that a road lasts much longer over a morass than when made over rock.

The first operation in making a road, should be to raise it above the ordinary level of the adjacent ground; care should particularly be taken, to have a sufficient fall to take off the water, so that it should always be some inches below the level of the ground of the road.

Having secured the soil from under-water, we should next proceed to secure it from rain-water, by a solid road made of clean dry stone or flint, so selected, prepared, and laid, as to be perfectly impervious to water; and this cannot be effected unless the greatest care be taken that no earth or other matter, that will hold or conduct water, be mixed with the broken stone; which must be so prepared and laid, as to unite with its own angles into a firm, compact, and impenetrable body. The thickness of such a road is immaterial, as to its strength, for carrying weight; this object is obtained only by providing a dry surface, over which the road is to be placed as a covering or roof, to preserve it in that state; experience having shown that if water passes through a road, and fill the native soil, the road, whatever may be its thickness, loses its support and goes to pieces, particularly when spring breaks up after a severe winter.

The size of the stones which McAdam recommends is six ounces for the *maximum*, and these are to form the whole bed of the road. The depth of solid materials should be from ten to twelve inches, and should be put on with care, in shovel-fulls and not by emptying a cart load down at a time, as it is of importance that the stones should be well mixed. The whole should be well rolled with a heavy roller.*

* When it is required to Macadamize an old *common-road*, the upper stratum must be removed and the convexity reduced. The stone taken from the old road must be broken and reduced to the size above given. In some cases only a layer of stone is required to convert an old road into a Macadams roads.—Tr.

CHAPTER XII.

Considerations on the Formation of different Profiles of Roads, with respect to locality.—Profiles of Roads in Level Countries—Details of their parts.—Catchwaters for draining off the water.—Cuts—Causeways and Ditches.

Roads should be considered with respect to their locality, as in a plain or mountainous country; the situation causes some essential differences in the profiles.

We shall first establish the preliminaries and such definitions as the consideration of position requires.

The *directrix* of a road is a right line, which, with the slope, determines the position of the road in space.

The horizontal projection of the directrix, is called the *Alignement.* The alignement, in the acceptation adopted by the corps *des Ponts et Chaussées*, is the projection of the directrix, or a part of the directrix itself, whether this be a right line or curve. A road is supposed to be generated by the movement of its transversal profile parallel to itself and perpendicular to the alignement.

The solid of the road should correspond to the ground which determines its base.

The draught of a road forms a plan of itself, and serves to determine the excavation and embankment of the *project;* it is the complement of the general plan.

Roads in Level Countries.

On level ground the principal alignements are right lines, and require but slight slopes.

Longitudinal slopes are determined upon the principle of an equalization of the excavation and embankment, by observing a medium between long slopes and short ones.

Perfect levels are to be avoided, particularly for stone causeways; because, in establishing a level road the transversal slope must be increased, in order to carry off the water, which is injurious and even dangerous for carriages

The greatest longitudinal slope allowed in a level country is $\frac{1}{18}$, or two inches to a yard.

Slopes in general, of course, must depend upon the ground, whose inequalities cause the plan or surface of the road to ascend, descend and ascend again.

A ramp which immediately follows a slope, is called a *counter slope*, and when a ramp is immediately followed by a slope it is called a *counter ramp*. The former occasions a gutter and the latter a ridge; these should be rounded by curves, one concave and the other convex.

The gutter formed by the passage of a slope to a ramp receives the water, which runs along the road with a velocity proportionate to the height of the slope, and in quantity according to the length of the slope, which renders it necessary to construct an artificial work in this place to convey off the water; this work is called a *catch-water* or *water-table.*

The breadth of the catchwater is limited by the quantity of water to be conveyed off.

An opening of three to six yards is given to it, and $\frac{1}{18}$ of this for the *flèche* or *sagitta;** it should be paved.

If the catchwater is made in an embanked part of the road the slopes at its extremities should be made in dry stone masonry; sometimes an over-fall is constructed.

All catchwaters require a ditch at the *up stream* extremity, to direct the water, unless the catchwater is in an embanked part of the road, in which case it is absolutely necessary to cover the slopes with masonry.

Catchwaters are liable to many objections; they are dangerous in the winter on account of the ice. Culverts are preferable when the locality will permit.

Besides catchwaters perpendicular to the axis of the road, there are broken and oblique ones. Broken catchwaters are employed where the slope is strong, and carry off the water to the right and left. Broken catchwaters are preferable to the oblique ones, because the former obstruct the passage of carriages less than the latter.

Oblique catchwaters are particularly adapted to mountainous localities.

The necessity of removing the rain water to prevent its injuring the road, particularly where there are long and deep slopes, has caused the adoption of other works for this purpose; *cuts* occupy the first place. These cuts are

* The *flèche* or *sagitta* in this case, is one half of the diminution made in the breadth of the road at the place of the catchwater, as there is a *flèche* on each side. —Tr.

a species of *traverses* made of rough stone,—sometimes in pavement, and cross the wings, the prolongation of which towards the axes makes with this same axis an angle of 100 to 120 degrees, the highest of which is towards the *origin of the slope*. These cuts are used as conservators of the wings on roads where the transversal slopes are long and high, and exceed the limit $\frac{1}{18}$; it has been found, however, that they are the cause of great injuries, in consequence of the water forming deep ruts in the wings, but more particularly in consequence of the ridges which the work causes. It is now renounced in all judicious constructions.

The *maximum* of transversal slope to be given to the wings is $\frac{1}{12}$ of the breadth of the wing, as we have before mentioned (*Fig.* 3, *Plate* 1). The *minimum* slope to be given to the wings, which occurs in sandy soils, is $\frac{1}{24}$.

In the profiles of ancient roads, the bottom line was a right line and horizontal, but in modern roads it is an arc of a circle concentric with the exterior surface of the road. Experience has confirmed the advantages of this modification, which reduces without injury, the thickness of the ancient causeway. The total thickness of the modern causeway, is ($0^m.40$) about fifteen inches instead of ($0^m.60$) two feet, which was the thickness formerly allowed.

The transversal profiles shown by *Figs.* 1, 2, *and* 4, *Plate* 1, are those most generally employed for level situations, adopting such a construction for the causeway as the locality affords; but as we have already said, there is another species of profile which may be employed with advantage in both level and mountainous countries, and which has the property of keeping the wheels of carriages upon the causeway; this is the reversed profile. (*Fig.* 3, *Plate* 1).

In this profile the wings are inclined in a direction contrary to that of the causeway; but it is evident that this can be used only when the causeway is paved; there will be a gutter formed throughout the whole length of the road, consequently this disposition will supersede the necessity of ditches on each side.

It may be employed on small declivities which do not prevent the continuation of the alignement which passes

over them, and compel us to turn and contort the road in order to pass the rise, thereby avoiding considerable excavations.

The wings which in roads of the first class should occupy two thirds of the whole breadth, should evidently be reduced for the other classes.

When the wings are suppressed (as on a gravelly soil) and the causeway occupies the whole breadth of the road, the slopes of the ditches and embankment should be defended by masonry; in which case depôts for materials must be made at intervals along the road. On considerable declivities the wings should be preserved, because wagoners will in preference drive upon this part of the road, and it is better to expose the wings than the causeway; it is essential to remove every cause of injury from this part of the road. By raising the road half a yard above the natural soil we may avoid the expense of ditches. This mode has some advantages; but it is evident, works must be constructed across the road to convey off the water. A culvert is sometimes sufficient; it should be ($0^m.48$) 1½ feet at least in breadth. When a culvert is not sufficient, a bridge must be constructed.

A road constructed across a marsh, or similar soil, should be built upon a grillage, when not made of fascines. Holland furnishes many instances of roads made with fascines. The Peten dike is a splendid example of this mode of construction; the fascines are placed under the embankment upon the marsh. The ancient dike, which the new one corresponds with, was constructed many centuries since, notwithstanding which, the grillage and fascines are in a perfect state of preservation at this time.

This singular method of constructing roads upon a marshy soil is very expensive, and should never be employed except when circumstances absolutely require it.

CHAPTER XIII.

Considerations on the direction of roads in Mountainous Countries.—Determination and Calculation of the Position of Catchwaters in Mountainous Localities.—Economical, Commercial, and Military Considerations upon Routes for Roads.—Tracing and levelling of Right-line Alignements.

DEFINITIONS.

The Causeway of a road, is that part of it upon which heavy carriages are intended to travel.
The wings of roads, are those parts upon which light carriages and foot passengers should travel.
The metalled part of a road, is the part covered with small stones or gravel.
Rampant plane, is a plane tangent to the highest apparent point of a hill, when it is conditioned to pass through a certain line.
Line of greatest declivity, is a line the rampant plane drawn perpendicular to the intersection of this plane with the ground.
Crest, is the top ridge of a hill or mountain.
Terrace wall, is a wall which supports an embankment of earth.
Banquet, as used in our work, is a bank of earth.
Cordon, is a row of stone, &c.

Roads in Mountainous Countries.

The profile and direction of this kind of roads, in order to satisfy at the same time the conditions of economy, solidity, and facilities for travelling, present many difficulties.

It is but a short time since the direction of this kind of roads has been perfected.

It is well known that the most perfect line of road would be that which is straight and level. But this can be had only in a country which is perfectly flat, a circumstance which rarely can happen. But when the intervening country is broken into hill and dale, or if one ridge of hills only intervenes, a straight line of road is seldom compatible with perfection. In this case, which is almost general, the greatest skill is necessary in tracing the midway between the straight and the level line. The best line for agricultural purposes, is to be calculated, by the time and exertion, jointly considered, which are required to convey a given burden with a given power of draught from one point to another. On great public roads, where expedition is the principal object, time alone may be considered.

The regular method of finding out the true line, between two points, where there is no other obstruction, but that presented by the ground; is to mark at proper points, the straight line. If the straight line be found ineligible, each mark serves as a rallying point, in searching on each side of it, for a better.

It may perhaps appear surprising, that there is but little difference in the length between a road that has a gentle bend, and one that is perfectly straight. A road ten miles long, and perfectly straight can scarcely be found, but if such a road could be found, and if it were curved, so as to prevent the eye from seeing further than a quarter of a mile of it, in any one place, the whole road would not be lengthened more than one hundred and fifty yards. It is obvious that, when the arc described by a road going over a hill, is greater than that which is described by going round it, the circuit is preferable; but it is not known to every one, that within certain limits it will be less laborious to go round the hill, though the circuit should be much greater than that which would be made in crossing the hill. When a hill has an ascent of no more than one foot in thirty, the thirtieth part of the whole weight of the carriage, of the load, of the horses, must be lifted up, whilst they advance thirty feet. In doing this, one thirtieth part of the whole load continually resists the horses' draught; and in drawing a waggon of six tons weight, a resistance equal to the usual force of two horses must be exerted.

On the sides of mountains, where the road is part in excavation and part in embankment, the breadth is reduced to ten yards, and sometimes to eight yards.

Long reaches or developments should be avoided when the direction of the road is not that of the mountain slope, as they increase the length of the road without much advantage; in such cases we should use a little stronger slopes, not exceeding the limit, however, of $\frac{1}{7}$, or about 5 inches to a yard. But when the declivity is parallel to the direction of the road, smaller slopes may be employed. The profile of a road upon the side of a mountain does not require the same details as one on level ground; it degenerates into a right line, which is inclined towards the excavated part. This disposition is indis-

pensable in order to procure the means of conveying off the water from the exterior bank of the road, which is always in embankment, into the ditch or drain (which crosses the road) at the foot of the excavation.

Like roads on level ground, this profile should be reversed or else a level profile, (*Fig.* 8, *Plate* 1.) and is composed of a causeway supported by a wing on each side, a slope to the embankment and excavation, and a ditch. The construction of the causeway does not differ from that on level ground except in the *form*, which, instead of being a curve, is a right line inclined towards the mountain; the exterior surface is parallel to it. The manner of placing the borderers, and the three layers, is the same as for a road in a level country.

If in consequence of favorable circumstances, the directrix should be tangent to the plane of declivity, which is very favorable with respect to expense, the transversal profile will be half excavation and half embankment. But, if in order to avoid placing the road in embankment upon a considerable declivity; or if, in consequence of a rectification of the first line, we should be obliged to carry the directrix into the hill, parallel to the rampant plane of the line of the plan, then the excavation exceeds the embankment. This excess of excavation may be employed usefully in forming a *banquet* upon the embanked wing of the road; it will serve as a safeguard to carriages, and as a foot-path. The *maximum** of excavation is made when the whole profile enters the mountain, in which case the breadth of the wings is diminished, and even suppressed.

In this case, which often occurs when we have been compelled to take an adverse direction, and abruptly leave the side of the hill to pass the summit, and from thence to assume a new direction, the reversed profile cannot be used; the curved causeway is then used with two ditches. The slopes are covered with stone; and when the excavation is great, the slope should be cut into a banquet of one or two yards in breadth.

In some cases, in order to arrive at the crest of the

* Few people are aware of the great expense of cutting and embanking; as in the case of a small hill it is generally thought preferable to carry a road straight through it, to winding round it, as then it is said that what is excavated will serve to embank the hollows on each side. It is preferable in almost every case to ascend the hill by various windings, always avoiding abrupt angles.—Tr.

elevation, when the distance is short, the reversed profile may be continued; in this case, only one ditch is necessary, but a catchwater must be constructed to carry the water from the embanked side into the ditch.

In order to diminish still more the quantity of excavation, the ditches are suppressed and a concave causeway established which collects the water in its middle; this causeway must always be paved. This last profile (*Fig.* 7, *Plate* 1) has many bad qualities. It evidently cannot be constructed of earth or gravel, since it is to serve as a drain for water, as this would soon be destroyed by the friction of the water : under these circumstances the paved causeway should be adopted; but this construction is expensive, and experience has shown that when the longitudinal slope is considerable, this species of causeway, during the winter, is slippery and absolutely impassable for carriages ; consequently this profile can only be employed in the southern states, and where the slopes are small.

When the *reversed* profile, which requires only one ditch, is employed, it will be necessary to establish catchwaters and culverts at intervals to dry the ditches frequently.

The means of conveying off the water rapidly is a very important general principle.

The most advantageous situation for a road in a mountainous country, as we have already stated, is upon the side of a mountain where it may be half in excavation and half in embankment.

The primitive position of the directrix, as given by the leveled line of route is frequently modified by rectifications and turnings of the successive alignements which compose the primitive line. If the declivity is great, a part of the embankment must be supported by a terrace wall,* which may be either in dry or wet masonry. The economy of the former renders it preferable.

When this species of wall is constructed, it should receive a slope of $\frac{1}{4}$ to $\frac{1}{6}$ of its height; the stone necessary for its construction will generally be obtained from

* The popular method in England, says Mr. Strickland, for preserving the slope of embankments, is to remove the sods from their base, which are placed upon the slope, the grassy surface perpendicular to the plane of the slope.—Tr.

the excavation, and these walls frequently, without augmenting the expense, may receive a great thickness. Terrace walls in lime are an object of luxury, and are generally found near cities; this species of wall should have an inclination of about $\frac{1}{12}$. Openings must be constructed to convey off the water. When a locality obliges us to adopt the *maximum* of longitudinal slope, and when this is combined with a considerable side declivity of the mountain, it will be necessary for the security of travellers to construct a railing along the exterior crest of the embankment, or what is still better, build a banquet or supporting wall. Precautions should be taken to defend the foot of the embankment on the side of a road, when a river runs along it, by a *cordon* of large stone; a terrace wall is sometimes employed for this purpose, but it is not always sufficient, under some circumstances a cordon or row of piles is necessary to defend this.

When the locality is rocky and there are salient masses which the line cannot avoid, the road must be reduced to its least breadth.

Sometimes, in order to avoid expensive excavations, the slope of the excavations of this part of the road is made corbel-like; this mode of construction is not without its objections, and examples of its use are raré. Besides, this method is not practicable where the rock is liable to be injured by the cold; under such circumstances there is no other method than to pierce the mountain and form a subterranean passage. The new roads to Italy (from France) over *Mont Cénis* and *Simplon,* furnish splendid examples of this species of construction.

On a rocky soil a space for the *form* cannot be excavated. The rock should be excavated, however, about 6½ inches, in order to place the two superior strata of broken stone, which are indispensable, whatever may be the hardness of the rock upon which the road is established.

Changes in the profile, either to reduce the breadth or vary the form to make it correspond with the locality, should be made at the points where the alignement is broken.

These changes should not be abrupt but gradual. This principle is applicable to all kinds of roads.

In cases of change in the profile, accidental slopes and penetrations, which result from it in the various solids of the causeway, do not require great precision.

The ridges should not be large, but as small as possible.

Roads in mountainous districts require numerous means for conducting off the water, as well as for carrying them over water, such as brooks and rivers. There are five means of accomplishing this end according to quantity of water, or the size of the stream over which the road is to pass. These are Ditches.—Catchwaters or water-tables. —Drains or Tunnels.—Culverts.—Bridges.

The Ditches are made on the lowest side of the road, when the reversed profile is used, into which all the water from the surface of the road is conducted.

The Catchwaters are shallow ditches made across a road to catch the water which might run along the longitudinal slope of the road, and conduct it into the ditches. Grieg (*App. to Strictures on Road Police, p.* 219) directs that they should be laid six feet wide at the bottom and flat, and twelve feet on each side, to rise one inch in a foot; which will make them one foot deep; laid in this way no carriage will feel any jerk or shake in passing it.

Drains and Tunnels. These are such works as are made for carrying off the surface water when it is collected in the ditches; they are more particularly used in the embanked parts of a road, as shown on fig. 8, Plate 1. In common cases these may be square, and about eighteen inches wide, covered with strong flag stones; the bottom of these should be paved or flagged, and there should be across each end a deep large stone, sunk below the surface of the current, and under the walls, to prevent the water from undermining the work.

Culverts, are arched drains of considerable dimensions for the passage of small streams. There are two cases, where culverts are required. 1st. When the walls of the culvert are to support only embankment. 2d. Where the walls are to support excavation and embankment.

We propose to give the method of determining the various parts of a culvert in both cases.

The most convenient arches for culverts not exceeding 16 feet span is the semicircular; culverts however seldom

require to be more than 10 or 12 feet; beyond this they are called bridges.

When a road is wholly in embankment, or the culvert is to be placed upon the immediate surface of the ground, is the first case. See fig. 32, Plate III. By a reference to the description of the plates at the end of our work the details for this and the second case may be fully understood.

The details for bridges will be found under its proper head in a succeeding part of our work.

Roads in mountainous countries cannot be adorned with trees, on account of their narrowness and the aridity of the locality, as well as from the nature of the ground. However, this advantage is given them when circumstances will permit.

In mountainous situations there are frequent occasions for catchwaters, and when the reversed profile is employed, the catchwater should be oblique to the axis of the road, and is then called an oblique catchwater or scarf. It should be paved.

The most advantageous position for this work will evidently be that which has the greatest slope and least length.

In our researches for the most advantageous position for the oblique catchwater, we must avoid placing it in the diagonal of the parallelogram formed by the four wheels of a carriage. The graphical determination of this angle, which is to be avoided, is easily obtained.

The solution of the problem to find the most advantageous position for a catchwater on the reversed profile belongs to *Elementary Geometry.** We shall terminate our

* Let DB and BC (*Fig.* 12, *Plate* I.) perpendicular to each other, represent the projections of the cross and longitudinal profiles of the road, let the two parts AB and BC represent the unit of measure, n representing the cross slope, and m the longitudinal slope; we will suppose the latter greater than the former; we wish to determine the projection DE of a catchwater which shall have the greatest slope possible.

In order to find in the angle DBC, the line BE of greatest declivity, it is necessary to find in the rampant plane of the road a line CD which shall be horizontal; then if through the point B we draw the line BE perpendicular to CD it will evidently be the line sought, consequently we shall have the projection of the angle which the catchwater makes with either of the profile projections. Since $m > n$, it is evident that the point D which shall be on the level with the point C, will be found in the prolongation of AB, and we may easily find the point D, since the distance which it is from the horizontal plane passing through B, is measured by $(AD + AB)\,n$ which must be equal to $BC \times m$, or making $AD = x$, $(x + 1)\,n = 1 \times m$; consequently $x = \frac{m-n}{n}$; and $DB = \frac{m}{n}$. And by comparing the

observations on catchwaters with one remark; when a road crosses a valley and the water is conveyed off by means of a catchwater, its opening should always be placed in the most advantageous position for agriculture.

Although we have fixed in a general manner the *maximum* longitudinal and transversal slopes, yet the tenacity of the soil upon which the road rests should be considered, as well as the effect of water upon this soil, particularly in determining the slopes.

After this exposition of principles, upon the construction of profiles and their accessories in mountainous countries, it will be easy to choose that which is most proper for economy and solidity for any particular locality. But this is not sufficient for forming a *plan*. Details for the operations upon the ground are necessary, the method of tracing a road must be known as well as the considerations which should influence us in a choice of directions, under different commercial and military views.

As soon as the proper authority has determined upon opening a road and designated the points of departure and arrival, the examination of the different routes, and the choice of the most advantageous, concerns the engineer only.

A complete examination of the ground is necessary.

It is necessary for the engineer after having determined by his first examination, although in a provisional manner, the practicability of the work, to draw a topographical plan of the country over which it is to pass; after which the levellings will be made to fix the position of the road, with respect to the ground, and fix the directrix; finally, he must support his project by a *mémoire* in which he will give his reasons for the choice he has made, in order that the government may be enabled to decide definitively upon the route, and give its sanction, which must always precede the execution.

two triangles DCB and ECB, we have

$$\cos. DEB \text{ or } ECB = \frac{1}{\sqrt{\frac{m^2+n^2}{n^2}}} = \frac{n}{\sqrt{m^2+n^2}}.\text{—Author.}$$

The general principles for tracing a route for a road are

1. The route should pass through as many inhabited places as possible.

2. Departing from one extremity of the route, the alignements should tend as nearly as possible to the other extremity.

Commercial considerations are important for roads in the interior of a country; but when a road approaches a frontier which it is to cross, the engineer should consider the direction in a military point of view. In such cases, the road should pass through such places as defend the frontier, in order to facilitate the communication between these places; the engineer should choose such alignements as are not commanded or enfiladed from ground beyond the frontier. If it should be necessary to join the road to a bridge upon the frontier, beyond which the neighboring power may construct defensive works, the road should join the bridge by a curved alignement, which will be defiled from the opposite works.

It results from our general principles for determining the line of route for a road, that the projection of the axis of a road, either on level or mountainous ground, presents a number of right lines forming various angles with each other. These angles must be rounded or cut off. Before we give the graphical methods of tracing these roundings, we shall point out in a few words the manner of tracing the line of a road.

We have already said that the axis of the road projected upon the surface of the ground, is the alignement.

This alignement is a right line or curve.

In such parts as are curved we cannot trace it upon the ground, as upon paper. Various methods are employed, all of which consist in obtaining intersections of right line alignements. A right line alignement is established by means of stakes. When the extreme points are given, we place a number of intermediate stakes in the same vertical plane; this is very simple and easy. Frequently after having traced a long alignement we do not arrive exactly upon the extreme; in which case the total difference should be measured, and each stake displaced according to its distance from the extreme point. When the extrem-

ities of an alignement cannot be seen at the same time, we must have recourse to trigonometry.

The above methods are applicable to small distances; when they are considerable, a plan upon a large scale is necessary, in order to obtain upon the ground, by turning to avoid obstacles, points in the route. In all cases, when the obstacle is removed, the route should be rectified by direct observation.

On level ground the alignement is the first element of the plan. The curves most in use for breaking the angles of right line alignements are the circle and parabola.

Changes in direction of alignements should be made on the highest points, in order to conceal them from the eye.

There are various methods of rounding the angles, the description of which will form the subject of the next chapter.

CHAPTER XIV.

Graphical Methods of Changing the Direction of Roads.—Theory and Practice of Levelling.—Application of the Spirit Level.—Methods of Recording a Level. —Theory of the Generation of the Ground between two Transversal Profiles.

Graphical Methods of Changing Direction.

Divide the angle *ABC* (*Fig.* 15, *Plate* II.) into any number of equal parts, by means of the theodolite or compass placed at *B;* mark the intersections of the lines *A*1, *A*2, &c. with *AB;* repeat the same operation from *C*, until the angle *ACB* is equal to *ABC;* the curve drawn through the points of intersection will be the arc of a circle; the intersection of lines which equal angles subtend, compared in an inverse order, evidently gives an arc of a circle.

Second Method.

Divide *AS* and *SB* (*Fig.* 16, *Plate* II.) each into an equal number of equal parts. Afterwards join each point of division of *SB* with the corresponding point of *AS;* the intersections of these lines will form a curve which will

be tangent to the alignements AS and SB in the points A and B.

This method, which gives a parabola, is the most simple and easiest to be executed upon the ground.

The changes in direction of two consecutive alignements should have such a development that the wheels of carriages may always be kept upon the causeway.

When the general plan of a road is determined upon and traced, the extremities are marked by setting strong stakes, and by lesser stakes for the intermediate points; they may be propped up with earth; sometimes we even construct masses of masonry, where the importance of the points requires it.

The curves of alignements should not be traced until we are ready to commence the construction.

Changes in direction are more frequent in mountainous countries than on plains. These changes are made by means of the second method, which is particularly applicable to roads on uneven ground.

Examples of Changes in Direction forming an Inflection.

Let $ASS'a$ (*Fig.* 17, *Plate* II.) be the zigzag formed by the lines we wish to modify by an infection, and let A be the point of infection. We may apply to the two angles at S and S' the second method.

These practical methods of rounding the angles of alignements are not always susceptible of direct application in mountainous localities, on account of obstacles which will prevent our dividing the lines as given above, and tracing the intersections. A more uncertain method may be substituted, which experience and skill renders expeditious, and which answers all the essential conditions of the problem.

This method consists in tracing successive cords forming a polygon in the angle to be rounded. *Fig.* 18, *Plate* II. shows the practice of this method upon the ground. Suppose we have the angle BSA, formed by the intersection of two alignements which it is required to round by the above method.

Take upon the line AS any distance $A\,a$, equal to ten yards for example; from the point A as a centre, with a

radius equal to $A\ a$, describe the arc $a\ m$, of a convenient length, then draw $A\ m$, making with AS any angle; then prolong $A\ m$ to n, making $m\ n$ equal to $A\ a$; then from m describe the arc $n\ n'$ with the radius $m\ n$ equal to $A\ a$; and thus continue the construction to the end of the change. It is rare that we succeed in our first attempt to trace the required curve; but the augmentations or diminutions of the cords may be made in a short time, and with a little skill the required polygon may be obtained.

This method may be employed for changes on level ground, but in order to avoid the uncertainties of this method it is better, when obstacles do not oppose, to employ the methods before given.

We have already said that the line of a road in a mountainous country is entirely governed by local circumstances, to which it must yield; the tracing of which requires particular methods. It is not, as in a plain, the result of a preliminary figure traced in the closet upon the map of the country; the route of a road on uneven ground must be traced upon the ground itself, and at the time of laying it out; but before speaking of the methods used in such cases, we must give a few of the details of levelling. The general object of levelling is to determine the difference between the distances of any two points of the earth's surface from its centre; or to determine a line, every point of which is equidistant from the same point, which is called the *line of level*.

There are two kinds of level, the true and apparent.

The true level is a curve parallel to the surface of the earth.

The apparent level is a tangent to this curve. (*Fig*, 14, *Plate* 1).

The air level which is used for tracing routes for roads on level ground, and in general, all instruments used for levelling, give the apparent level only.

There are tables calculated for determining the exterior parts of the secants, which is the expression for the distance which the tangent or apparent level is above the true level; and which serve to correct the operations

when the distances between the instrument and points of level are not equal.

This problem of common Geometry, gives for a distance of 2000 yards a difference of about 132 lines which the true level is below the apparent level.

Levellings for the construction of roads seldom require this correction; as we should be careful to place the instrument in the middle of two points of level. Each station is composed of two sights, back and fore, and compares the level of at least two points of ground, in a longitudinal level, that is, along the axis of the road; the one is called the *forward sight*, and the other the *back sight;* other observations, if any are made, are called *intermediate sights*. The heights of the points of level are marked by two sliding rules, called *levelling staves*. They usually consist of two staves 10 feet long, that slide upon each other, and are divided into 1000 equal parts; being numbered at every tenth division. Each stave is furnished with a vane of sight. Each station forms a simple level. A combination of several simple levels, is called a *compound level*. Each part of the simple level is attached to the compound one by a *back sight*, which joins the *forward sight* of the preceding station, and consequently gives the relation between the two stations. (*Fig.* 10, *Plate* 1).

In order to level with any degree of accuracy, the distance between the points of observation should not exceed thirty yards each, from the instrument, when the air or spirit level is used.*

As many observations are taken at each station as are necessary for the project. The instrument is then removed to the middle of the portion of ground to be included in the next observation. It is evident, that it is not necessary to place the instrument in the alignement. The visual rays always being in a horizontal plane, they will determine, with respect to this plane, the relative height of any number of points of the ground, whatever may be the position of the instrument. A certain order is necessary in writing

* For surveys of *examination* made by the United States Topographical Engineers it is customary to take levels of 10 to 20 chains (when the ground will admit of it) or 220 or 440 yards, and the instrument is placed in the middle of this distance.—Tr.

down the observations, which must always be done upon the ground and at the time of making them.

The method adopted by the *Ponts et Chaussées* engineers is to write the numbers representing heights at the sides of the perpendiculars to the horizontal line representing the *line of level*, the number representing the *back sight* is placed on the right, and the *fore sight* on the left of these perpendicular lines. The extremes of a simple level are marked upon both sides when several are connected together, except the first and last; intermediate levels have but one on the sides of the perpendicular lines.

Between these perpendicular lines we trace the irregularities of the ground; this is necessary to avoid errors.

Upon the horizontal line, between the perpendicular lines, are marked the horizontal distances between them. *Fig.* 11, *Plate* 1. represents the field-book or minutes of a longitudinal level with the corresponding cross levels. Evidently all these should be referred to one station, the aggregate of which forms a compound level. This reduction is the preparatory work, previous to plotting the level.

Preparatory to plotting the work we commence by subtracting the least from the greatest of the forward and back sights; or begin at the origin of the level and subtract the forward from the back sight, if ascending, and the reverse if descending; the difference is *plus* or *minus*, plus indicating *rise*, and minus *fall*.

These differences should be placed between the perpendiculars, each between its two, of which it is the difference in length. The level thus prepared on the field-book, we assume, in order to determine the distance of the first point below any assumed line, a certain distance which exceeds the sum of all the ascending *levels*, in order that every point of the level may be referred to this line; all the succeeding ordinates are some function of this primitive one. The lengths of these ordinates are written in black, in contradistinction to the ordinates of the *plan* which are marked with red, of which we shall shortly speak.

When these new references are constructed, the level is plotted.

If we wish merely to know the difference of level of the two extreme points of a line, it is not necessaryt o plot the work for this purpose, it may be obtained by adding together all the *plus* references, and all the *minus* references, and taking the algebraical sum of these; and as this sum is plus or minus, we know which extreme is the highest.

All levels, even for roads, which do not require so rigorous a precision as for canals, require verification.

To verify a level made for a road, we assume long levels of 200 or 300 yards; we do not measure (the distances between) them however, and if we find nearly the same results, corresponding within a few inches, we may conclude that our first level was sufficiently exact.

Levels made for hydraulic works should be made with the greatest care, and with the best of instruments; each simple level should be verified, and at different times, until exactly the same results are obtained.

For the laying out of a road a longitudinal profile is not sufficient, it is necessary to know the ground to the right and left of this; this knowledge is gained by means of *cross levels*. As many cross levels should be made as the nature of the ground requires. These levels have one point common with the longitudinal profile; by means of these cross profiles we obtain a complete knowledge of the whole surface of ground over which the road is to pass.

These cross profiles are distinguished by numbers which show their relation to the longitudinal level.

At the time of making a level for the route of a road, the earth should be sounded, in order to ascertain its nature; in fine, every fact should be noticed which may serve to fix the route.

The cross profiles taken in pairs establish the relief of the ground. From one profile to another is a polyhedron solid, with warped surfaces for some of its faces, and generated by the movement of a right line parallel to a vertical plane passing through the axis of the road, with its extremities resting on the two profiles. This generation of the ground is adopted in order to facilitate the ulterior operations.

This hypothetical generation of the ground is different

from that adopted by the late senator Monge and M. Meusnier, for the graphical solution of the problem of defilement, in which the ground is represented by curves made by horizontal sections at different heights, that embrace all references of equal dimensions.

This method was necessary for Meusnier's object. The method above given is sufficiently rigorous for the plans of roads.

The cross profiles are perpendicular to the directrix, and divided into a sufficient number of parts, and in such places that an intermediate reference is not necessary in order to represent the ground exactly.

All the above details upon levelling are applicable to roads in level countries; in mountainous localities, another and more expeditious method is employed. The above is but seldom used, and then by multiplied operations, in tracing roads in mountainous countries.

CHAPTER XV.

Levelling for a Road in a Mountainous Locality.—Application.—New Principles applicable to this Species of Roads.—Establishment of Slopes and Ramps upon a Plotted Level.—Calculation of the Vertical Red References.—Method of obtaining these at the Time of Levelling.

The best instrument for tracing a route for a road in a mountainous country is the *theodolite;* this instrument is susceptible of great precision.

The line of sight may be varied from zero, which is horizontal to the greatest ramps and slopes employed. This variableness is obtained in consequence of the telescope moving in a vertical plane. This instrument marks the arcs of the angles, and a *vernier* shows the fractions of degrees.

When the axis of the telescope is placed parallel to the slope of the project for the road, the line of sight will pierce the ground in points of the line, when placed in the given direction. This instrument accelerates much the operation of laying out a road in mountainous places; by means of it we may try several routes at the same time.

By placing the instrument in the valley and elevating the line of sight so as to make it parallel to the slope allowed, the telescope may be moved round, and the most favorable point ascertained.

It should be observed, that the above relates to laying out a road and its parts.

The best instrument for levelling is the *air* or *spirit-level* with a compass. With this instrument the courses and levels may be taken at the same time.

The mode of using any instrument is best learned from an examination of the instrument itself, with the instruction of a skilful teacher.

No person ever learned the handy use of instruments from a book, although the principle may be clearly communicated in that manner.

In all surveys, whether for canals, roads, rail-roads, or for the establishment of artificial harbors, the country should be triangulated; it is the most expeditious and by far the most accurate. A base for the triangulation of a locality should be selected with a view to making the triangles isosceles if possible, and the stations should be selected with this view for the angular points.*

Before beginning the route of a road which is to be developed upon the side of a hill, passing from the valley at its foot, over the crest, a complete knowledge of the ground is necessary, particularly of the beds of the valleys which branch out from the principal one along which the road passes; as the road should follow the bed of the secondary valley which approaches nearest to the direction the road should have in this part of the route, provided all other local circumstances are equal. Facilities for development, and the use that may be made of them for establishing slight slopes, are circumstances which should not be overlooked.

But when the point in the valley, and the point on the hill where a road is to pass its crest are given in position by local circumstances to which the route is subjected, it is necessary that the development should be made between

* Maps for canals, roads, and rail-roads, should be drawn on a scale of about two inches to the mile for the plan. The horizontal distances for the profiles should be on the same scale as the plan, and the vertical distances should be six times the horizontal ones.—Tr.

these two points; and if the direct development should be such as to give ramps exceeding the fixed dimension of three inches to a yard, the engineer will be obliged to form zigzags in order to obtain ramps practicable for carriages. This kind of line has many inconveniences, and should never be used until all others have been tried and have failed.

It is easy to ascertain the practicability or impracticability of a route by means of the theodolite. The instrument should be placed at the point of departure in the valley in such a manner as to be able to see the point where the road should arrive upon the hill; the telescope then should be inclined so as to bring the line of sight upon the point last mentioned. The line of slope given by the visual ray, differing but little from the actual inclination, we may judge by that, whether the elevation is too great for the plan to be adopted, and whether we are to adopt the direct or zigzag route. When the theodolite is not to be had, the engineer, before determining the route to be adopted, should make a particular level of the ground between the two points in order to ascertain the height of one point above the other; it will also be necessary to measure the distance between these two points, and dividing the absolute height by this distance, we shall have the inclination per yard.

The engineer, it is true, may abridge the labor of levelling, by using the portable barometer, and calculating his results by means of the *formula* given by M. de Prony in his *Cours de Mécanique.* When the difference of heights does not exceed 1200 or 1400 feet, we may obtain their relative situation with sufficient accuracy for the route of a road, but we are always obliged to measure the distance between the two points; so that the application of the barometer to the tracing of routes of roads is not so advantageous as the theodolite, but is excellent for the reconnoisance of a locality for the summit level of a canal.

In all cases of a road in a mountainous country, it is a general principle not to employ ramps of an uniform length throughout the whole road, but to place the longest at the commencement of the ascent, diminishing as we approach the summit.

This distribution of ramps between the points of departure and arrival, is intended to diminish the labor of the horses in proportion as their strength diminishes. This principle is not rigorous, and may be departed from when it will diminish the expense.

Economy and solidity require that a road on the side of a hill should be half in excavation and half in embankment. We have already spoken of this principle when speaking of cross profiles as applicable to this species of roads.

In order to satisfy this condition, the route must follow all the inequalities of ground, and of course the line is a number of curved lines, salient and re-entering.

The curved alignement should pass through such points as are given by the level; these points may be sacrificed to beauty, however, when they produce disagreeable combinations. The ratification, however, of which we shall soon speak, must never depart from the true line except locality and expense admit of it.

When there are points through which the road is required to pass, and from which we cannot depart without great injury, these points divide the total plan into several partial plans, and generally increases the difficulty; while on level ground this circumstance will frequently facilitate the establishment of a route. The gentlest slopes should be placed at the angle of the zigzags; they serve as resting-places for carriages.

A southern exposure, when circumstances will permit, is preferable for laying out a line of road.

Such are the general principles for tracing a road in a hilly district or region.

Before speaking of the details necessary for obtaining such corrections as the primitive line is susceptible of, we shall return to plans on level ground, and indicate the labor to be performed in the closet for determining from the plotted level, the slopes and ramps, the aggregate of which forms the plan of the road; a knowledge of these operations is necessary for the rectification of routes on rising ground to which they are applicable.

The longitudinal level plotted, and combined with the transversal levels, are essential considerations for tracing

slopes. Economy in *embankment walls*, equalization of embankment and excavation, and facilities for travelling, are considerations which determine the slopes to be adopted. Lines of slope and ramp should be as near the original ground as possible. Ascending in order to descend, and then ascending again, should be avoided when not absolutely necessary.

The slopes of roads of the first class near large cities should be at least 600 yards in length. This length may be reduced for roads of less importance to 4, 3, and even 300 yards.

Direct principles may fail in determining the slopes and ramps for a particular route; but in this case the experience of the engineer should point out the best plan to be followed.

We may try one route; if it does not answer, we may begin again; in fine, in order to compare and choose with a perfect knowledge of all the circumstances between several results, it is necessary to calculate all the terracing required for each route.

The determination of the problem for equalizing the excavation and embankment is not capable of a rigorous calculation.* However, the consideration of the slopes projected upon the longitudinal profile furnishes sufficient data for the provisory determination of this question.

A certain number of profiles are considered at a time, and then modified by an attentive examination of the results to be perceived at one glance, by augmenting or

* In order to determine the quantity of excavation and embankment, let (*Fig.* 31, *Plate* III.) $b\ m$ represent any portion of the road, say 20 yards in length, and suppose A and B to represent the profiles at each extremity, $a\ b$ represents the inclination of the road, and is equal (for the maximum) to $\frac{1}{20}$ of $b\ m$. Suppose $x\ y$ to represent the profiles of the ground across the road at b and m. Now if we pass any vertical plane, perpendicular to the profiles, it will cut the planes of the road and ground in two lines, the space or spaces included between these two lines will show the earth to be removed, or to be added, as the case may be. Suppose CD to represent the trace of a plane perpendicular to the profiles, revolve this plane down and HE will represent the line cut from the ground, GF the intersection of this plane with the plan of the road, and we here see that the planes of the ground and road intersect in O; consequently the triangle GOH represents a section of the quantity of earth to be removed, and EOF a section of the quantity to be added; and in order that the excavation shall equal the embankment, these two triangles should be equal; and the same condition is necessary for every other section.

Of course, in practice, we shall never find the ground a right line, but still our method is sufficiently exact.

This is the method taught by that excellent instructer, Professor Douglass of the United States Military Academy.—Tr.

diminishing the number of profiles; finally, we make the best disposition of the ground circumstances will admit of, regarding the essential conditions of economy in the terracings, and facility in travelling.

To supply the defect of rigorous principles in this respect, we may make trial of a plan of slopes, and give our reasons for their adoption upon a part of the plotted level.

The determination of the slopes and references which result from it, and which show the embankment and excavation, is very easy. We shall give the most simple method. The references to the plan, are called *red references*, because they are generally written in red ink; while the references to the ground are in black.

Let P be the absolute or total slope of the line of the project $A'B'$ (*Fig.* 19, *Plate* II.) for any distance x, p its slope for one yard, T the absolute slope of the line Aa of the ground for the same distance; p' its slope for one yard; let the horizontal distance $Ao = x$, and the known red reference $AA' = d$.

This being supposed, take the point A of the ground as the origin of the axes of co-ordinates; then the equation of the line Aa will be

$$y = p' x.$$

And that of the ramp $A'B'$

$$y = px + d.$$

Subtracting the former of these equations from the latter, we have for the value of the red reference sa

$$\left.\begin{array}{l} y' - y = (p - p') x + d. \\ y' - y' = P - T + d. \end{array}\right\}$$

So that the red reference sought, is equal to the excess of the absolute slope of the road over that of the natural ground, increased by the preceding known red reference.

It is evident that the above formula, which is general, applies to an ascending slope or ramp, but may be applied equally as well to a descending slope, by changing the signs agreeable to the rules of algebra.*

This closet operation may be dispensed with, however, and the slopes and red references determined upon the

* By the application as above, we may determine the point or points in which our plan for a road passes above or below the natural surface of the ground. *Figs.* 20, 21, 22, exhibit the three cases. We have omitted the algebraic work, it being exceedingly simple, only involving the simple line.—Tr.

ground itself, the whole being determined by levelling. This method, besides abridging the labor of the engineer, has the advantage of showing immediately the quantity of supporting walls, which result from the rectification, and consequently shows if they be admissible, or if another and more economical one must be sought.

The method and order of this operation are indicated in the following table; it presents the formula and all the given parts necessary in order to find by simple addition and subtraction the red reference of every point of the line.

The red references found by this method agree with those calculated by the above formula, and consequently establish the correctness of this method; in other respects, it is easy to consider all the circumstances of ground necessary.

The formula for the red references is $(A \pm P \pm C) - B = C'$. C is the red reference of the *back sight:* C' is the red reference sought. A is the back sight, and B the forward sight.

The signs of the quantities P and C must be taken in the following order:

For P { + When it is a slope.
— When a ramp.

For C { + When *déblai* or excavation.
— When *remblai* or embankment.

TABLE, *showing the Slopes and Red References of a Longitudinal Level.*

Number of Stations.	Distances between the Stations.	Ramps — Slopes + for the whole distance.	$\pm C$ Excavation + Embankment — at the extremity; origin of the slope or ramp or red side at this extremity.	Levels for each Station. Back A	Forward B
1	"	0.0	— 4.62	" "	" "
2	15	0.15	— 3.29	2.56	0.72
3	15	0.51	+ 2.36	6.26	0.10
4	18	0.61	— 0.88	0.89	3.52

CHAPTER XVI.*

Preliminary Observations on Appareil in general.—Application to the Construction of Bridges.—Ovals or Basket-handle Curves.—Comparison of these with the Ellipsis.—Details on tracing large Arches with Arcs of Circles.

The art which determines the forms which materials should have to form any particular species of building, when applied to stone, is called the *appareil.*

In the general acceptation of the word *appareil,* as used in architecture, it means merely the apparent forms of masses when combined together to form a building.

A perfect appareil requires regularity and even beauty in its form, and solidity in its results. In order to obtain this double condition the *apparent appareil* is often limited by the *appareil proper.* In all cases, it is necessary that when the whole mass is divided by the appareil, it should give the forms required, as well as the stability the mass possessed before division.

A right wall may be considered as a rectangular prism; this may be divided without disturbing its stability, into several horizontal laminæ; the stability is the result of

* The chapter preceding this, in the original, has been omitted by the translator as being inapplicable, except the mensuration, to the American student, instead of which he gives the following as containing the same principles applied to the United States.

Much precision is necessary in calculating the quantity of excavation and embankments, which is done by the common rules of mensuration.

The earths may be removed with the pick-axe and shovel for short distances, and with barrows and carts for longer ones. Thus if in digging a canal, drain, or foundations, if the soil is soft and require no other tool than the spade, a man will throw up about 27 solid feet per hour, or 270 cubic feet in a day of ten hours. But if picking be necessary, an additional man will be required; and very strong gravel will require two. The rates of a cubic yard, depending thus upon each circumstance, will be in the ratio of the number 1, 2, 3. If, therefore, the wages of a laborer be one dollar per day, the price of a yard will be ten cents, for cutting only, twenty cents for cutting and digging, and thirty cents when two diggers are required. When wheeling is necessary three men will be required to remove 30 cubic yards in a day, to the distance of 20 yards, two filling and one wheeling; but to remove the same quantity in a day, to a greater distance, an additional man will be required for every 20 yards.

To find the price of removing any number of cubic yards to any given distance.

Divide the distance in yards by 20, which gives the number of wheelers; add the two cutters to the quotient, and you will have the whole number employed; multiply the sum by the daily wages, and the product will be the price of 30 cubic yards. Then as 30 cubic yards is to the whole number, so is the price of 30 cubic yards to the cost of the whole.

From the above data it is easy to ascertain the cost of excavation and embankment.

It may happen that the embankment is some distance from the excavation or the place where the earth is to be obtained to make this embankment, in which case the cost of transportation will be considerable; it will be found most economical to borrow the earth from the side of the road near at hand.

This is a vicious practice, however, and should not be followed unless it is absolutely required.—Tr.

the inertia of the sum of these masses. This prism may also be divided vertically, but in order that the mass may have stability, the mass must be divided in such a manner that each portion may rest upon a plane portion of the inferior mass.

We have already said, when speaking of cut stone masonry, that the limit of each horizontal division is called a *course;* and each vertical division a *joint.* The cutting planes, the edges of which form the limit of the course, are called the *beds of the courses,* and the planes of the joints, *the beds of the joints.* The horizontal beds of the courses are parallel, and to produce a pleasing effect should all have the same height; it is then called *regular-coursed* masonry.

It is evident that the vertical joints should not be continued through the whole height, but should be so modified that the middle of one stone should be placed over the joint of the two inferior stones; this is called *breaking joints.*

Such is the most natural system of appareil for a right wall; it is not the same for bridges. It is necessary that the appareil be such, that the tendency to movement towards the interior be counteracted by a tendency in an opposite direction. It is evident that the elementary solids forming the arch of a bridge cannot be rectangular prisms; their extremities must be unequal.

The smallest end of these masses is upon the interior surface of the arch.

These solids are called *voussoirs,* and have the form of a wedge.

It is necessary that the *voussoirs* be equally resisting on all sides, but more particularly upon the two faces forming the *beds of the joints,* which must be normal to the curve of the arch; this principle is rigorous.

It follows from our preliminaries, that flat arches are not susceptible of a rigorous and determinate appareil.

We are indebted to Senator Monge for the general solution of the problem of appareil; he remarked that the large and small joints constitute two classes of curves on the visible surface of the arch, and that the beds of the joints should be *developable* surfaces.

The interior surface of an arch is called the *intrados*, and the exterior the *extrados*. The sides or surfaces visible from a point of the stream above or below the bridge, are called the *heads*, and when these surfaces are perpendicular to the axis of the arch, it is called a *right arch*.

Arches for bridges, when their axes are perpendicular to the axes of the roads leading to them, present no difficulties of appareil. The number of courses of *voussoirs* in a *right arch* is generally determined by the thickness of the quarry beds from which the stone is obtained, and the quality of the other materials.

The only difficulty in the appareil, is the joining of the *voussoirs* with the horizontal courses of the piers and imposts. In common architecture, and for small arches this connexion is made in a manner admissible to a certain extent only ; this method is called the *elbow appareil;* that is, instead of placing a vertical joint over the meeting of a horizontal course with its corresponding *voussoir*, this vertical joint is carried back, to the right or left, a certain distance, and thus forms an elbow. See *Fig*. 23, *Plate* II.

The elbow appareil is not carried to the top of the arch, in consequence of the fractures produced by the unequal sinking of arches, after the decentering.

Elbows may be employed from the origin up to a certain height ; such of the voussoirs as constitute a part of the horizontal courses, are called *butment stones*.

Figs. 23, 24, and 25, *Plate* II. show the various methods of connecting the *voussoirs* with the horizontal courses of the piers and imposts, in such a manner as to permit the arches to settle without danger of breaking the stones.

The appareil of arches, the curve of which is composed of arcs of circles, commences at the impost. If the base of the cushion rested upon the impost, it would form with it an acute angle, and three visible edges would meet at this point. In order to avoid this defect we generally lower down the inferior surface of the top course of the cushion, so that the arch springs from above it. See *Fig*. 34, *Plate* II.

Curves, Ovals, or Basket-Handles, applied to the Construction of Arches.

Of all the curves which can be employed to form the arches of bridges, the semicircle, or the *full centre,* as it is called, is the most beautiful and simple. The ancients almost universally adopted it.

It cannot, however, be applied to all localities. It sometimes raises the bridge too high, and renders the access difficult.

The *full centre* gives great breadth to the supports and tympans. This form, evidently, is not advantageous for the flow of water, for in proportion as this rises during freshets, the opening diminishes. These causes limit the application of this curve to particular localities, and generally to arches of small span.

Flat arches satisfy the condition of a large opening best; but this form cannot be often employed, because of the difficulty of construction, independent of the great expense for abutments, which must be of large dimensions on account of the great horizontal pressure or thrust.

After the *plat-band* arch next in order, comes the arc of a circle; this also has the objection of a great horizontal thrust.

Architects, generally, have preferred an eccentric semi-ellipsis, as the curve best suited for arches of bridges; it is a mean between the semicircle and arc of a circle.

Local circumstances determine the ratio of the semi-conjugate to the transverse axis; the former is called *the rise* of the arch, and the latter *the span.* The rise varies from $\frac{3}{4}$ to $\frac{1}{4}$ of the span.

The difficulty of drawing an ellipsis on a large scale, causes the oval to be preferred, as it is constructed with arcs of circles and approaches very near to the former curve, and the centres of curvature of the oval are given, which furnishes facilities for drawing the joints of the *voussoirs* normal to the curve.

In order that this curve may be tangent to the *piedroit,* it is necessary that the sum of the arcs which compose it should be equal to 180°, and that the smallest arc have its centre upon the diameter of the arch.

All ovals (*Anse de Panier*) have an uneven number of centres.

Generally, this curve has three centres, except we wish a very flat arch.

The rise and span being given, analysis indicates the method of finding the centres. The most elegant solution is that given by *M. Bossut;* but this problem belongs to that class called *indeterminates;* the equation of the second degree resulting from the analysis, determines one radius when the other is given.

In order to avoid this ambiguity, *M. Bossut* determined that the most agreeable oval to the eye, was that in which the difference of curvature was the least possible. (*Fig.* 29, *Plate* II).

In consequence of the above modification, it is neces sary that the geometrical ratio of the differences betweer the radii be a *minimum*, that is, that $d\frac{x+y}{x}=0$.

Performing the necessary operations for the solution of the equation according to the above considerations, we arrive at a very simple result, which gives the following geometrical construction for the curve of three centres.

The centres are the points of intersection, (*Fig.* 29, *Plate* II.) P and S, of the greater axes and the less prolonged with the line MS which is perpendicular to AD joining the two extremities of the semi-axes; the line MS divides the line $A\,d'$ into two equal parts, the line $A\,d'$ being equal to the difference between AD, and the line representing the difference between the two semi-axes. This method of construction, which is very ancient, is that most generally used in practice. Stone-cutters employ this method. There is another construction for the oval depending on the condition that each of the three arcs be 60°.

After having drawn a semicircle with BC for a radius, (*Fig.* 30, *Plate* II.) draw the chord $M'\,D'$ of 30° through the point D' where the curve meets the lesser axes produced; after which draw the chord $M'\,C$ equal to 60°; through the extremity of the lesser axes D, draw the line DM parallel to $D'\,M'$, and through M draw MO parallel to BM; then the points of intersection O and K will be the centres required.

This construction is frequently employed by the Corps *Ponts et Chaussées*, particularly when the difference between the semi-span and rise is small; when the rise is less than $\frac{1}{3}$ of the span, this method should not be employed, because of the great curvature of the small arc, which produces a disagreeable effect; in this case, we should employ a curve of a greater number of centres, as five, sometimes seven, and nine; for large arches eleven centres are employed. There are many beautiful examples of the use of the latter curve, the handsomest is the bridge of Neuilly, which was traced with eleven centres.

The conditions necessary to trace this curve with eleven centres, in order to obviate the indetermination of the problem are,

1st. That from p to a, (*Fig.* 27, *Plate* II.) the distance between the centre of the curve and the centre of the extreme arc, be divided by the radii of the other arcs into parts which are to each other in the arithmetical ratio of the natural numbers 1, 2, 3, 4, &c.

2d. That the distances between the prolongations of the radii, measured upon the lesser axes produced, be equal.

3d. That $p\,a$ be equal to $\frac{1}{3}$ of p V.

It remains then only to determine the centre a of the extreme arc, so that the curve may pass through the extremities of the axes. In order to determine the point a, considering the above quantities as given, we make use of a method as simple as it is ingenious.

Fig. 27, *Plate* II. shows the construction of a figure representing the position of the centres conformable to the above conditions, and by the simple analogy between the sides of these similar figures, we shall easily find the value of the abscissor $p\,a = x = (b - a)\frac{n}{m+n-S}$, S being the polygon a, R, Q, etc. m and n being the ratio between $p\,a$ and $p\,V$.*

* Agreeably to the conditions specified above, we shall have the following equations, $x + S = 3(b - x) + a$; where x represents $a2$ (*Figs.* 26 and 27, *Plate* II). It will be found by calculation that the sum S, of the sides of the polygon in this case is equal to $3.25\,(b - x)$ nearly; therefore by substituting this value in the equation above, we have $x + 3.25\,(b - x) = 3\,(b - x) + a$, from whence $x = \frac{4a - b}{3}$.

Tr.

In order to find a value of x we must have the value of S, which is unknown; this may be found by means of the angles. The process is very long; but may be abridged by means of a graphical construction upon a large scale.

Any ratio may be taken between m and n, which, in the present case, is 1 to 3; any augmentation of this ratio will increase the radius, and consequently diminish the curvature.

For the construction of an arch, a pattern of every stone is necessary when the curve is not a semicircle.

The patterns are drawn upon the draught of the size to be used in constructing the required work.

In order to draw a complete draught of an arch a large space is required; when we have not a building of sufficient dimensions, a stand must be erected of the extent of the arch, generally in masonry and covered with a thick coat of plaster.

In order to obtain a complete trace, after having determined the position of the centres, the two extreme arcs are described with a pair of beam compasses; but when the radii become considerable this method must be renounced. The remaining portions of the curve are traced by means of points determined by calculating the co-ordinates of the extreme points of each arc; the chords are then drawn, and the sagittas, which are easily calculated, will give a point of the curve. We obtain two intermediate points by drawing new chords between the middle and extremity of the arc, and thus we may successively have as many points as are requisite for tracing the curve, by means of a flexible rule, applied to the determined points.

When the chords become very small the calculation of the sagittas may be dispensed with, as in this case they are equal to a quarter of the saggitta of double the last found chord.

By means of the points of intersection of the radii with the horizontal axes, the direction of the radii of curvature may be determined, and consequently, the joints of the stones. For the intermediate voussoirs, as their lengths are very small compared with the radii, the sines of the arcs may be taken as the arcs themselves; consequently

for the points of division of the voussoirs (*Fig.* 28, *Plate* II.) if we draw a parallel $a' b$ to the radius of curvature, we may determine, by a simple proportion, the value of $a' b'$ perpendicular to this line, which measures the departure of the two points. For this result to be accurate it is necessary that $a' b$ be about three yards in length.

All the facts above mentioned, respecting the details of making draughts of large arches, are drawn from the experience of engineers, who have been particularly engaged in the construction of such works, the success of which is strong testimony in favor of these methods.

CHAPTER XVII.

Wing Walls—Principles of their Appareil—Details on the Pressure of Arches and Earths—Principles of forming a plan for a Bridge—Character of the Architecture proper for such works.

DEFINITIONS.

The axis of a bridge, is a right line drawn through the middle point of each extremity.

Key stones of an arch, are the middle voussoirs.

Débouché of a bridge, is the breadth of the river or stream at the water line.

Developable surface, is such as can be spread out, or unrolled; as a paper cylinder may be cut lengthways and enrolled into a plane.

Abutment piers, are the piers or abutments of a bridge placed in the river banks.

Socle, is the piece of stone work shown on *Fig.* 33, *Plate* IV. A *dye* is shown on the same figure.

Corbels, are projections from a wall, forming a shoulder.

There are two modes of sustaining the earth of an embankment to a road joining a bridge.

The first is by means of a stone wall; the second is an epaulement. The first method is employed when there is a great height of embankment required. Sustaining walls at the entrance upon bridges may be established in two modes; either in the prolongation of the heads of the bridge, or making an angle with them; when the latter, they are called *wing walls*.

Supporting walls in the prolongation of the *heads* should have such a length that the profile of the slope of the bank

of the river may not extend to the opening of the arches; and if the bank of the river is confined, a banquet will be necessary between the foot of the slope of the bank and the edge of the channel, unless the slope of the bank be in masonry, when the banquet may be dispensed with.

When a *wing wall* is preferred, the slope of the embankment should be terminated by a quarter of a cone, one of the faces resting against the prolongation of the *head*, and the other on the slope of the river bank.

The joining of a road to a bridge by means of the quarter of a cone is a method which pleases the eye, and gives but little opportunity for the action of the water, besides giving an additional resistance to the abutment.

When a return wall is constructed, the coping course of stone should be established in the plane of inclination of the embankment; in this case there is economy in the masonry, since the profile presents a triangle; but the earth is liable to injuries which can be remedied only by care and constant repairs. Economy prescribes that these walls have only such a length as is absolutely necessary; consequently, they should be placed perpendicular to the heads, but in this case the opening should embrace the whole breadth of the river; the limit to the length of these walls should be the base of the slope of embankment. These walls are generally terminated at their extremities by a socle crowned with a dye.

Instead of being vertical, if the wing walls are constructed with an inclination it gives them a flare which is advantageous for the *débouché*.

Plate 5, shows the projections of the various parts of a wing wall for a culvert.

The divergency resulting from an inclination of the walls is frequently insufficient, and a more considerable opening indispensable, to prevent floating bodies from injuring the bridge.

When we have only the latter condition to satisfy, it is customary to give the walls an inclination to the axis of the bridge; the exterior line of the base generally has an inclination of 22½°, to a line parallel to the axis of the bridge, when a right arch.

This constant divergency of 22½°, however, can only be employed when the course of the river is not confined between high banks, or when the length of the base of the embankment is such as to meet the edge of the channel, forming an angle of 22½° with the abutment. Instead of employing this dimension constantly, it will be much better in many respects, to let the flare depend on the locality and the position of the base of the embankment, with respect to the crest of the river bed.

In order to obtain the most advantageous angle, a necessary condition is, that the plane of the inclined surface of the wall and dye shall abut against the slope of the bank in order to support it, as the wing wall cuts it obliquely.

It is very rare that the bank of a river is higher than what the road should be to enter upon the bridge; wing walls in this case would be useless; the intersection of the plane of the slope of excavation, with the plane of the river bank, forms a salient angle, which is defended by masonry. The embankment, if any, on the prolongation of the *heads* between the bank and the abutment is supported by a small wall; this disposition is far preferable to return walls; the planes of their faces would cut the bank and produce a bad appearance and an odd appareil.

The horizontal joints which are at the same height in a wing wall, are all in the same plane.

The vertical joints are perpendicular to these same planes. The planes of the courses are not continued out to the end slope of the wall; they are stopped and turned perpendicular to the line of slope. This *letting-in*, which is about three inches in length, prevents the stones from sliding out. Before entering into the details necessary for constructing a bridge, we shall notice two essential points in the art of construction, the pressure of arches and earths. The solution of problems relative to these points involve physico-mathematical considerations of a delicate nature, which have led to the disagreement of former solutions.

For the pressure of arches, it is necessary to determine the position of the point of rupture, which will divide the arch into two parts, one pressing and the other resisting. The abutments are considered to be either overthrown, or

to slide away. The adhesion of mortars is another important consideration.

Several engineers and geometricians of the first reputation have occupied themselves on the investigation of this problem, but all having proceeded upon different hypotheses, their results do not agree.

The late Perronet, First Engineer of the *Ponts et Chaussées*, convinced of the cause of the great discrepancy in their solutions, endeavored by experiments made upon a large scale on the arches of the bridge of Neuilly, to determine the point of rupture.

Lines of comparison were marked upon the heads of the arches; these served to show the direction and quantity of movement after the centres were removed, and the arches left to their own weight. The bridge of Nogent, when experimented upon, showed an inflection, resulting from the action of gravity; and the point of rupture in this bridge was found at the distance of $\frac{1}{6}$ of the arch from the point of support. In the Neuilly bridge the joints of the voussoirs opened between the twenty-sixth and thirty-first voussoir, that is, a little below the middle of the arch.

The latter result approaches very near to the hypothesis formerly adopted by the academician La Hire.

The late M. Chezy, *Inspector General of Ponts et Chaussées*, calculated tables from La Hire's formula, and determined the point of rupture conformable to these experiments for a full centre and for an ellipsis. Both suppositions are favorable for the resistance. These tables have been used with success for determining the dimensions of the abutments, of all the large bridges, which have been constructed of late years in France.

They also give the thickness of the piers for arches of full centres, and for those lowered one third, for all spans and diverse heights of abutments and piers, as well as for different weights of earth and pavement; finally, they give the thickness of the keystone. Long experience and constant success has established a confidence in these tables; they are used by the Corps *Pontes et Chaussées*.

Many distinguished philosophers have exercised their talents on the solution of the problem of the pressure of

the earths; in all the solutions previous to that of M. Prony, the adhesion and friction of the earth were disregarded. M.Prony, from the suggestions of M. Coulomb, has given a complete solution of this problem, considering the cohesion and friction, by applying the principle of maximum and minimum. The pressure of a differential prism which rests immediately upon the slope which earth naturally takes, is nothing, if any value is given to the cohesion. This value is nothing, also, for a differential prism in a vertical position.

Between these two limits, there is a position where the prism would have a maximum of pressure. This consideration of the maximum of pressure renders all former solutions defective.

M. Prony has demonstrated in his "*Mécanique,*" and formerly in a "*Mémoire,*" printed in 1802, for the use of students, that the position of the differential prism at the maximum of pressure, is such, that its inferior surface makes with a verticle line an acute angle, which is equal to half the angle earth naturally takes.

This law establishes the connexion existing between the formula for earth that takes a slope, and that for water which does not.

In the latter case the angle which the slope makes is zero, and the angle consequently which gives a maximum of pressure is 45°.

M. Prony has added to the theoretical solution, a graphical construction, which, when constructed with care, answers very well for determining without calculation the thickness to be given to walls under all circumstances.

This graphical formula which may be constructed by every constructor, should hereafter supersede the blind routine generally followed by those not versed in the calculus; it presents great advantages in expense and solidity; essential conditions for private constructions as well as public works.*

After having indicated the best curve to be employed for arches of bridges, and established upon principles, the correctness of which cannot be doubted, the most suitable arrangement, and the dimensions necessary for their

* See *Note* at the end of our work.—Tr.

accessory parts; we shall present such other principles as should govern the engineer in forming a plan for a bridge, in order to obtain the best construction possible for this kind of work. When it is required to form a plan for a bridge, the engineer should commence by drawing an exact plan of the locality, upon which should be indicated in a precise manner the breadth of the stream, accidents of ground, banks of gravel and sand which low water leaves, the islands, and the directions of the streets or roads which meet at the points contemplated for the bridge. It is not only necessary to know the points where the bridge crosses, but by means of soundings along the line of direction to obtain a complete profile of the river bed; likewise, it is necessary to know the quantity of water which flows through the profile, under all the various circumstances which may influence this quantity; to the plot of the level should be attached the high-water mark, and, where there are no tides, the height of the highest and lowest water; to these particulars should be added a sufficient number of soundings, in order to determine the depth of the water and quality of soil upon the different points of the profile, also at what depth we find a firm bottom; upon the map should also be indicated the position of a fixed point which will serve to lay out the different parts of the work when we come to construct it.

The axis of the bridge should be perpendicular to the course of the river, or as nearly so as possible, in order that the piers and abutments may be parallel to the thread of the stream; when circumstances prevent this disposition, the bridge should be oblique to the piers and abutments, an inconvenience preferable to placing the piers and abutments oblique to the course of the current, which should always be carefully avoided.

The principal parts, and their positions being determined, it remains to ascertain the number of arches, and consequently their spans, or what is the same thing, to fix the *débouché*. The rigorous solution of this question, if it were possible, would require the engineer to know exactly the quantity of water to which the bridge should give an opening, particularly during the greatest freshets, in order, that the openings may bear some relation to

this quantity, or else the velocity of the stream might carry away the piers and abutments. The experiments of *Du Buat*, who made great progress in researches on running waters, and the researches of *M. Prony*, whose corrected formula coincides with experiments, show that the mean velocity, an element necessary for calculating the volume of water which flows through the opening, was nearly equal to $\frac{4}{5}$ of the velocity at the surface.* We might by means of this quantity, if it were the only one, obtain a very exact solution of our problem; but the tenacity of the river bed is a necessary element in order to determine the limit of velocity which can be allowed.

In effect, if a bridge is to be constructed upon a rocky soil, the danger of undermining by adopting a small *débouché* will be obviated, while, if the river bed is composed of such substances as are capable of being raised by the current, it will be indispensably necessary to give the *débouché* a breadth nearly equal to that of the stream.

The best precaution under all circumstances, is to examine the openings of all bridges above the locality required to be improved, if any, in order to ascertain the velocity resulting from their openings, the effect of this velocity upon the bottom, and to observe if it does not occasion injuries which art is obliged to obviate; and finally, if the bottom is the same as at the place where it is wished to establish a bridge. If these particulars are found to be such as a judicious construction should always present, the same opening, modified according to the quantity of water should be adopted; the modification should be such that the mean velocity under the new bridge shall be the same, under similar circumstances, as that under the bridge which served as the unit of comparison.

The breadth of the entrance being determined,

* It might easily be shown that the velocity of a stream under a bridge depends either upon the nature of the bed or upon the quantity of fall that would injure the navigation.

If b represent the breadth of the natural water-way, and c the breadth as reduced by the construction of the bridge; also V the velocity per second in feet in its natural state; then the velocity v under the bridge will be expressed by the equation $v = m\, V\frac{b}{c}$, and $c = m\, V\frac{b}{v}$. Where m is a constant quantity which expresses the contraction a fluid suffers in passing through a narrow passage. Sir Isaac Newton gives it $\frac{25}{21}$ where the piers have square ends. Du Buat gives for an equilateral triangular form $m = 1.09$.—*Treadgold on Carpentry*.—Tr.

although the thickness of the piers and abutments has not been considered, but as their mass is an impediment to the current, they should be as thin as possible.

This principle, in one respect, limits the maximum of span, and in another, the rise; the minimum of rise is one fourth of the span.

The keystone, generally, is one or two yards above the highest waters.

When the best of materials are not to be obtained, arches of a medium span should be adopted.

As it is advantageous to have an opening in the middle of the river, we must always have an odd number of arches when we have more than one.

The adoption of arches formed of arcs of circles, suppresses many of the difficulties of construction with respect to the many local conditions to be satisfied, by combining what they require with the necessary *débouché*.

Arches formed of arcs of circles may spring from the high water mark and even higher, which facilitates the opening for the water during freshets; this species of arches is also advantageous for forming a tow-path under the bridge.

These combined advantages should cause this arch to be frequently employed.

It is useless to endeavor to increase the *débouché* when it is insufficient from local circumstances, by giving the abutments a retreat into the river bank, thereby augmenting the breadth of the stream; this enlargement is without the current; therefore the water will stagnate, alluvial deposits will be made, the river will be soon reduced to its primitive size; and the effects will soon be the same as before enlargement. If the abutments are contiguous to wharves already constructed, their front faces should be upon the line of these wharves. Notwithstanding, if the bed of the river between the wharves is broader than necessary, we may carry the abutments out, and reduce the opening to such a breadth as is strictly necessary for the bridge.

An opening too broad is injurious as well as a contracted one; it occasions decreations which increase very

fast and injures the opening in case of a freshet. The saliency of the abutments into the river facilitates the access to it, and gives it beauty. The breadth of a bridge between the heads is always proportional to its importance; there are many examples of breadths form 8 to 16 yards; in large cities they are made still broader.

In general, bridges are not so broad as the roads leading to them; the contraction is made at their extremities either in the form of a shoulder or circular. The shoulder form is advantageous for facilitating the entrance upon the bridge.

Local considerations sometimes prevent the ready establishment of these shoulders; they are frequently placed upon pendentives, and sometimes even on corbels from the extreme arches; the latter method, however, leads to inconveniences in appareil.

Experience, confirmed by success, has given a practical method of determining the thickness of the keystone of large arches. To the $\frac{1}{24}$ of the span, add the constant quantity ($0^{m}.32$) about 1 foot, from which sum subtract $\frac{1}{144}$ of the span, the remainder is the thickness of the arch at the keystone.

Lately there has been much difference of opinion respecting the conditions to be fulfilled by piers. However, it is from the consideration of their functions that their thickness is to be determined.

Some wish to form abutments for each arch; others, among whom are several celebrated engineers, think that the opposite thrusts should be regarded as nothing, since they are nothing for equal arches, and consequently the piers will only have the weight of the arches to support.

Upon the first hypothesis the piers should have the same thickness as the abutments. According to the second theory the piers should have twice the thickness of the keystone; this voussoir being more compressed than any other, this thickness is strictly necessary; but in the construction of some large bridges lately, where the piers are upon the second hypothesis of resistance, they have been made a third or a fourth thicker than the theory prescribes.

This system gives a great saving in materials, and it may even be said that it increases the solidity of the bridge by diminishing the causes of an undermining, which has been the ruin of many bridges. The piers of the bridge of Neuilly are constructed upon this supposition.

The employment of this system requires the best of materials, the certainty of a good foundation, and a well established regime in the bed of the river; it also occasions some extra expense for centreing, as all the centres must be constructed at the same time.

In this case it is also necessary to give the piers the same thickness below the lowest water as if they were considered abutments.

When an engineer is called upon to construct a large bridge over a river liable to frequent and strong freshets, the bottom of which is not stable, he must evidently reject the system of *thin piers*, since the fall of one would draw after it all the others of the bridge.

Abutment-piers must be constructed in such cases, however, in order to diminish the inconvenience of contracting the bed and consequently of a less *débouché;* only two or three abutment-piers may be constructed in the centre or most exposed part of the bridge.

This method, which has been practised by several engineers, divides the whole bridge into several parts, which permits the adoption of the advantages of the second hypothesis by diminishing the inconveniences of the first.

The heads of bridges are defended from injury by floating bodies above and below, by means of projections from the piers, called *starlings* or *cut-waters*.

In ancient bridges the starlings generally had a prismatic form, the base of which was an isosceles triangle, sometimes it was an irregular figure composed of two arcs of circles, the thickness of the pier forming one side and the radii.

The starlings should be elevated above the highest water. They are crowned with a plinth; and terminated by a solid called a *hood* or *chaperon*, the form of which in modern bridges is variable. The most simple and agreeable is a flat semi-cone. This is the form used on the bridge of Neuilly.

The triangular starling is not generally used; the semicircle is more preferred.

Sometimes, the piers of decorated bridges have the form of a pilaster, and sometimes they are prolonged up to the entablature which they support.

The Blackfriars bridge, at London, has its piers surmounted by a group of small columns which rise as far as the entablature, the object of which is to enrich the imposts.

The achitecture of bridges recommendable only on account of its large masses and boldness of construction, admits of but few of the ornaments which frequently disfigure this species of constructions.

All the necessary dimensions for a bridge being determined as well as the requisite accessories, such a style of architecture should be given it as best suits the locality and nature of the work.

A large bridge in a horizontal position, is generally acknowledged to produce a fine effect; this disposition also permits the introduction of some of the riches of architecture, which generally produce a bad effect when the bridge has considerable rise.

When it is not practicable to have a level roadway, but we are obliged to adopt an inclined one, proceeding from the centre, it should not have an inclination exceeding $\frac{1}{24}$, or half an inch to a foot.

The heads of bridges are generally crowned with a moulding composed of a torus, fillet, and cavetto; this crown is simple and well adapted to this species of constructions. Sometimes cornices are used, which, however, should be composed of as few pieces as possible, and strongly marked. Consoles and modillons should be reserved for bridges in large cities. The architectural character of bridges should correspond with the locality; simple and plain upon roads; bold, rich, and varied in cities.

In general, it is the style of the surrounding monuments and local considerations, which should determine the achitecture of a bridge.

CHAPTER XVIII.

Continuation of the Preparatory Operations for constructing a Bridge.—Foundations.—Piles.—Driving of Piles, Piers, and Pile-Planks.

It is not sufficient to insure the solidity and durability of a bridge in masonry, that the dimensions of the masses, which should resist the pressures acting against them, have been determined from established rules and correct formulas; it is also requisite that their bases be firmly placed, in order that the weight of the work may not cause ulterior changes. This base is called *the foundation.* It is a general rule to descend so low that the base may rest upon a stratum of earth which presents a density and resistance sufficient to support the intended work.

When the soil which is to support the building is not dense enough, we are compelled to seek a firm bottom, in which case we are obliged to excavate to such a depth as will give it; often this is impracticable, in which case art furnishes an auxiliary means, whereby we may give to the base the required stability.

On the good choice of this auxiliary depends the reputation of an engineer, and it is principally in the construction of hydraulic works that great difficulties occur; the obstacle, water, in the midst of which we wish to establish our work, and the necessity of placing it upon a bad soil, cause the foundations of edifices to be regarded as one of the most difficult operations in the art.

Engineers, generally, distinguish three species of soils with respect to their good or bad qualities for laying a foundation.

The first class comprehends the hard soils, such as rock of all kinds, turf, and stony soils, which can be attacked only by means of the mine or pick-axe.

The second, is the gravelly and sandy soils, which are incompressible when confined.

Finally, the third class includes all the earthy soils from the vegetable mould to clay, all of which are capable of being compressed.

The first class is evidently the best for establishing all kinds of foundations.

Observing the precaution of surrounding the space to be occupied by a pier or any other work, either with stone work, or piers and jointed planks, the earths of the second class are considered capable of supporting the base of any work. With respect to the third class it comprehends such soils as are reputed bad and present great difficulties either for consolidating, or obtaining throughout the whole surface of the foundation, an equality of compression which will insure the stability of the work.

It is important then, to know beforehand the quality of the soil upon which it is intended to place a foundation, in order to determine the best method of establishing it, according to local considerations and expense.

This knowledge of the ground is to be obtained by soundings made at short intervals, not only in the lateral direction but in the transversal, even beyond the breadth of the bridge.

For this purpose an iron instrument is used having notches at the extremity which enters the ground; these notches should be partly filled with tallow; it is forced into the ground by blows upon the superior extremity, either with a maul or mallet; it is withdrawn by means of a lever passed through the eye made in the head of the instrument, and the various strata of earth will be found in the notches.*

This examination should be carried as deep as possible, the instrument may be lengthened by joints fixed to each other by screws.

When firm bottom is at such a depth that the foundation cannot be placed immediately upon it without a great augmentation of the excavation and consequently of expense, or meeting with insurmountable obstacles, then piles are employed.

This method consists in driving piles into the firm soil, the heads of which are connected together by timber, forming a grillage or cob-work.

Upon this artificial platform the foundation is placed.

When firm ground is at a great depth and the strata which cover it are compressible, piles are not generally

* In the construction of very important works, this examination can be better made with an auger.—Tr.

used however; a foundation may be placed upon such a bottom, but it is better to employ other means which art furnishes to prevent the inconvenience of an unequal compression.

In this case it is better to form a mass of timber as large as the abutments and opening of the arch; the fluidity of the soil in a horizontal direction is opposed by means of a row of jointed piles which inclose the mass within an enceint called *a platform.*

The platform of *single-arched bridges* and others of small span are flat or in the form of an inverted arch, the intrados of which varies but little from the bottom of the stream. Experience has proved that in order to obtain a convenient profile for this work, when the inverted arch is employed, the sagitta of the curve should be such that if subtracted from the radius, the remainder shall be equal to one and a half times the span of the arch.

Following this rule, this platform can only be used for arches of a small span.

The platforms of large bridges are constructed in another manner, that is, the heads only are constructed in stone.

Let us return to the details for driving piles generally; at the same time present a few more considerations upon the establishing of foundations.

Piers differ from *piles* in this, the former have a part of their length above ground while the latter are entirely sunk.

The thrust of a pier or pile is the quantity which enters the ground before stopping.

The number and magnitude of piles evidently depend upon the magnitude of the foundation and the weight to be supported. The absolute negative resistance of wood is the only theoretical point applicable to piles and their driving; it will be sufficient to explain this.

It is known that cylindrical pieces of wood loaded at their extremities, the weight acting in the direction of the fibres, resist in the direct ratio of their diameters, and in the inverse ratio of the square of their lengths.

From experiments made at Havre on a large scale, by the Corps *Ponts et Chaussées,* it has been discovered that

a piece of wood 9 inches in diameter, elevated 3 feet above the ground into which it was driven, supported about 141875 pounds before breaking or bending.

Under nearly similar circumstances and the same weight upon each pile, one of the arches of the bridge of Tours, in 1777, fell down, the piles having broken and occasioned this accident.

Caution, when constructing works of importance, is necessary in conclusions drawn from experiments, particularly the above. Generally, an allowance of one half should be made.

Perronet recommends that the number of piles for the foundation of an edifice be determined in such a manner that each pile shall support (25000 kilog.) about 55172 pounds.

The rule for placing piles, considered with respect to the ground, which should not be too much compressed, is determined from experiments made upon a grand scale by the *Ponts et Chaussées;* the minimum distance between the centres is fixed at 2½ feet.

Dividing the total weight of the work by the number of piles, we shall have what each one should support.

Observing the modified law of resistance as above given, we may determine the diameter of the piles, if their number is given, or if the diameter is known we may find their distances apart.

A certain relation should be observed between the diameter and length of a pile, in order that the driving may be made with advantage; experience has shown that piles from 10 to 13 feet long should be from 9½ to 10 inches in diameter.

The driving of piles and piers is performed by means of percussion.

The machine used for this purpose is called a *pile-engine.* The body whose fall produces the effect is called *the ram.*

There are two kinds of engines. The first, which is in general use, is where the ram is raised by the main force of a large number of men by means of pullies; the other, where it is raised by means of machinery, and is used for driving large piers and piles.

The former engine has lately been improved. The weight of the ram in this engine is from (3 to 400 kilog.) 656 to 875 pounds, and the number of men such, that each one shall not have more than 30 to 35 pounds to raise, with a velocity of 4 feet per second.

This is the measure of the force of a man for a day of eight hours.

A volley is 30 percussions. After each volley the men should rest 30 seconds.

This intermission is advantageous not only for the laborers but for driving the pile, because it calms the tremulous motion produced by the percussion, which renders the succeeding percussions more efficacious.

In some cases a pile driven by the engine worked by machinery stops, when a ram of less weight would cause it to sink.

This is explained in the following manner; it is known that a certain velocity will sometimes produce a resistance capable of overcoming the motion resulting from it.

In driving piles there are two stoppages, the *absolute* and *apparent*.

The absolute stoppage is where the pier has descended to the depth of hard ground, after which it will descend no more than $\frac{1}{4}$ to $\frac{1}{6}$ of an inch per volley.

The apparent stoppage takes place when the friction of the pier against the ground destroys the motion produced by the ram. If we cease at the latter point without taking the necessary precautions, we expose the edifice constructed upon such a foundation to ruin.

In order to avoid this defect, which it is easy to do, we must diminish as much as possible the causes of friction, by barking the piers and sharpening them.

In argillaceous earth, which is not compressible in a great degree, only a certain number of piers can be sunk, beyond which the additional pier will force out those already driven. In order to avoid this, some engineers have stated that the larger extremity of the piers should be down.

When it is wished to consolidate the earth by means of piers, it is evident that they should be driven at the centre of the area first, going towards the circumference.

As it is important to accelerate as much as possible the driving of piles and piers in consequence of the expense of keeping the water out,* which is generally done during this operation, as many engines are used as possible for the space, and for the greater effect, the weight of the ram should be proportionate to the magnitude of the piles.

It is known that a percussion has a physical effect only so long as it exceeds a certain quantity of movement communicated, which is the measure of the resistance which a pile exercises against the load destined to carry it down. Mathematically speaking, there is no comparison between an active force and a dead one; however, repeated experience in driving piles shows that a certain pressure may put a certain percussion in equilibrium.

From the formulas for communicated motion, we have for pile-driving, $v = \frac{M V}{M + m}$; M being the mass of the ram V its velocity and m the pier or pile; v shows the velocity with which the sinking commences.

The sinking being proportional to the square of the velocity, that is to $\frac{M^2 V^2}{(M + m)^2}$, or to $\frac{M^2 h}{(M + m)^2}$; the square of the velocity of the ram being proportional to the height h of the fall. So that, for the same pile and ram, the sinking is proportional to the fall of the ram.

In sinking different piles in the same ground with different rams, each sinking is proportional to $\frac{M^2 V^2}{(M + m)^2} \times (M + m)$ or $\frac{M^2 h}{M + m}$. According to an experiment of Mariotte, the shock of a body weighing one *kilogramme* and three *centièmes* (2lb. 4oz. 6dr.) falling ($0^m.18$) about 7 inches, is equivalent to a pressure of (195 kilog.) 426 pounds.†

From this experiment, and the application of the above theory, a ram weighing (293 kilog.) 646 pounds falling

* Pile engines may be fixed to scows or boats, for the purpose of driving piles or piers in the water.—Tr.

† In computing the effect of a pile engine, it is first necessary to estimate the quantity of percussion that is equivalent to the resistance and friction opposed to the pile; as no momentum short of this, or even just equal to it, will produce an effect; when the momentum is greater, it is only the difference between the two that is effective.—Tr.

($1^m.29$) 50 inches will produce a percussion, whose effect is equal to a pressure of (399,106 kilog.) about 880, 785 pounds.

This quantity is the measure of the resistance of a pile, whether its stoppage is absolute or relative.

Reducing as we should this quantity to one half, the pile evidently may be loaded with more than (150,000 kilog.) 331,035 pounds, which is six times more than Perronet assigned to a pile for a foundation; but it cannot be denied, that there is great uncertainty in experiments of this kind, and that it would frequently be dangerous to employ rigorously the formulas given by such experiments, and consequently prudence dictates that we should follow the instructions of this skilful engineer and not exceed the weight of (25.000 kilog.) 55172 pounds for each pile.

The head of each pile should be squared and hooped with iron, to prevent it from splitting by the force of percussion. The hoop is removed after the pile is driven. When the ground is very hard the point of the pile is shod with iron; in which case care is requisite in placing the shoe so that the pile shall touch every part, which prevents it from splitting and thus retarding the progress of the pile.

When it is required, piers and piles may be spliced or lengthened. This splice may be made by two cuts or scarfs, agreeably to the principles of carpentry. This connexion of two pieces should be strengthened by two jointed hoops. When square timber is used, it should be spliced by the full scarf. This assemblage should be defended by hoops or bands.

A register should be kept of the driving of piles and piers, in which should be recorded the number of men employed and the length of each pile, its sinking at each volley, the number of volleys required to drive it *home*, and the length of the thrust. These records are useful, not only for determining the expense, but also to show the cause of settlings which sometimes take place during and after the construction.

The piers for scaffolds and coffer-dams, are not generally driven into the hard bottom, therefore the shoeing and other precautions may be dispensed with.

The driving being completed, the machinery scaffolds

may be removed, the piles cut off level, and the necessary dispositions made for placing the grillage.

If the ground is not firm and a caving-in is feared of the slopes of the excavation, a row of piles or jointed planks may be driven at the foot of the slope.

Pile-planks are a species of thin piles; they are made of timber from 12 to 16 inches wide and 4 to 8 inches thick. They are joined together by their thinnest edges; when very perfect joints are required, they are joined by the groove and tongue.

Pile-planks are employed with advantage in many kinds of hydraulic works, of which we shall hereafter speak.

CHAPTER XIX.

Grillages.—Coffer-dams.—Draining.—Tracing a Work.—Foundations by means of Caissons.

In order to show more extensively the application of our principles for the construction of bridges where we are obliged to seek a solid foundation at such a depth as cannot be reached by excavation, and we are obliged to use piles; we shall continue our details upon this supposition, as well as where we use a grillage.

The number of piles, their situation, and dimensions having been calculated agreeably to our rules above given we proceed to drive the piles within the coffer-dam, after which, if the soil is muddy or capable of but little resistance, about one foot of it should be removed and replaced by a layer of clay, or what is still better, lime masonry, which should be level with the shoulders of the tenons, which have been prepared in the heads of the piles to receive the grillage, upon which is to rest the first course of the foundation masonry; after which every thing is ready to receive the grillage.

The *grillage* is a species of frame work in wood, formed by letting the pieces into each other, the whole of which is to be supported by the piles; the timber should be so

placed that the points where the pieces cross each other may rest upon the heads of the piles.

When the ground offers sufficient resistance, or is not *very* compressible, and the dam is secured by piles or jointed planks, the grillage may be placed immediately upon the ground. This circumstance causes no change in its construction.

When a grillage is to rest upon piles, if in consequence of an irregularity in driving, frequently unavoidable, any of the piles should be out of the line, the tenon on the head of the pile is suppressed, and the grillage is supported on such by a shoulder; when this deviation is so great as to prevent this mode, the grillage is supported in such places by a piece of iron bolted firmly to the piles.

The mortices in the grillage should never be made until the pieces have been compared to the tenons of the piles. The *caps* form the frame of the grillage. The sleepers are the pieces placed parallel to the length of the work, and the cross-bars are such pieces as cross these at right angles.

The sleepers and cross-bars are connected together by a notch in each, or when they are not of the same dimensions the lesser one is let into notches made in the greater; the caps are prolonged beyond each other about a foot. These prolongations are called *catches*.

When the dimensions of the grillage are such as to require more than one length of timber, it should be spliced by using the *lap* and *scarf*.

When the grillage is to be floored, the sleepers may be omitted. The cross-bars are then called *beams;* and should not be so thick as the caps, by the thickness of the plank forming the floor, in order that the superior surface of the platform may be even when planked; therefore, the caps should have a groove to admit the plank.

When a coffer-dam is secured by pile-planks, they need not be driven until the band is placed against the interior vertical face of the piles, as they are to rest against it.

The platform which covers the grillage is made of plank of from 3 to 4 inches in thickness, placed so as to

form good joints and perpendicular to the beams, to which they should be attached by spikes or treenails.

Instead of filling up the spaces between the piles and beams with masonry, as we have already observed, it may be done with clay, and this method is good when the grillage is to receive a platform; these spaces whether filled with clay or masonry, should always be completely filled.

Some engineers are opposed to the use of platforms, particularly when the spaces between the sleepers and cross-bars are filled with masonry, it is said they serve as an intermediate body disposed between two masses of masonry, and prevent their connexion, and consequently facilitate slidings, which are liable to take place on account of the great horizontal pressure.

In opposition to these reasons, it is said that percolation may occur under the foundation which would inevitably cause the overthrow of the work, and that a platform will prevent this; this consideration has generally led to the adoption of this work, even at an increased expense. A platform may be made at a less expense than by planking; the spaces between the sleepers may be filled up with scantling of the requisite dimensions. This method will not facilitate the sliding of the mass since the inequalities in the surface occasioned by the unequal dimensions of the scantling and sleepers, will oppose any movement.

If it is required to construct a pier or abutment of masonry in a river, a dry space is required in order to drive the piles and place the grillage, which is to be obtained only by works of art.

For this purpose *dams* and *coffer-dams* are constructed, the heights of which, should be such that the highest waters may not overflow them.

The body of these works may be formed of vegetable earth; clay is better, as it has more tenacity, weight, and impermeability.

In stagnant waters, when not deep, an earthen dyke is sufficient, the earth having its natural slope.

When the work is to be placed in a river or the sea, a boxed coffer-dam is necessary.

This work is formed by driving two rows of piers around the space to be included from the work; these are about 4 feet 4 inches from centre to centre, the distance between the rows such as may be necessary to support the water. The piers of each row are connected together by a band or ribban placed near the top; tie-pieces are notched into these bands, and connect the two rows together. Pile-planks are then driven so as to rest against these bands forming the sides of the coffer-dam.*

In proportion as the box is formed, the bottom between the two rows should be dragged, and the mud and sand removed, down to solid bottom, which may be done by means of a machine for this purpose.

It is evident that the success of a coffer-dam depends essentially upon the care observed in its construction. The clay which should fill the space between the two rows should be well worked and placed on a firm bottom, in order to avoid filtrations which will infallibly take place if it is not placed on hard ground.

The *boxing* should be done with care, the clay should be placed in layers and well rammed with as little agitation of the water as possible, in order not to spread it.

It is necessary that the timber, of which a coffer-dam is made, should be placed in such a manner that the *grain* shall be perpendicular to the stream, the grain will conduct the liquid and cause filtration, which should be carefully guarded against.

By means of the common rules of hydrostatics, the thickness of a coffer-dam may be calculated, if we consider the resistance to be opposed to the pressure of the water, only with respect to the inertia of the mass; but the augmentation of the resistance occasioned by the piers and pile-planks is so great, and the probability of a rupture of these so small, and the solution of the problem so laborious, that, we are in some measure authorized to adopt the rule used by the Corps *Ponts et Chaussées*, the success of which long use has confirmed. The rule is, to give to the coffer-dam a thickness equal to the height of water to be sustained, when this height does not exceed (3 metres)

* In England foundations on piles are established by driving the piles first, then a coffer-dam is formed of cast iron sheeting piles around the space to be included; this method is both expeditious and cheap.—Tr.

10 feet; when it exceeds this height, one foot in thickness is to be added for every additional yard in height. When coffer-dams are placed in places exposed to currents they are liable to be frequently injured. In such cases it is necessary, when possible, that the *means* of repair should constitute a part of the ulterior works. A skilful engineer will draw many advantages from these accessory works.

After the barrier forming the coffer-dam has been completed, we should proceed to exhaust the water; this is accomplished by means of machines, more or less complicated, moved by hand, wind, water, or steam, according to local circumstances.

The most common machine used, is the chain pump, vertical and inclined; after which come Archimedes' screw and the simple scoop worked by means of a pole and shovel in the Dutch manner. The scoop, however, is applicable only to small depths, but when it can be used it is the most expeditious as the number of agents may be almost indefinitely increased. Under certain circumstances Archimedes' screw may be used; water may be raised a great height with it; besides the machine is very simple and requires but few repairs and a small number of men to work it. Vertical chain pumps require but a small space to work them and their produce is continual, but they require frequent repairs.*

The number of machines to be employed depends upon the space we have to place them upon, the quantity of water to be removed, springs and filtrations which cannot be anticipated; consequently, it is not possible to calculate the exact number required previous to commencing the work.

The most unfavorable case should be anticipated and provided for.

If economy requires that the least surface possible should be occupied, foresight dictates the anticipation of an interior dam sufficiently large for the free movement of the workmen.

When local circumstances will admit of it, the coffer-dam should be so constructed as to embrace a pier and an

* Chain pumps worked by steam engines, will be found the most economical and expeditious.—Tr.

abutment, so that a part of one dam may serve for a part of the succeeding one.

The form of a coffer-dam depends upon the figure of the work to be built in it, as well as local circumstances. Having removed the water from the interior of the coffer-dam and laid the platform, dispositions are made for raising the masonry; before commencing, however, the form of the work should be distinctly marked out upon the platform. In tracing this, it is important to fix the two axes or capital lines. The longitudinal axis may be fixed by means of the directing piers already fixed in the shores. Other piers may be fixed, upon the heads of which the line may be traced, they all being of the same height and in the line of the axes.

These piers may be used as scales for marking vertical and horizontal dimensions.

After the breadth of the stream has been accurately determined the middle may be marked by a pier, upon the head of which the alignement should be traced, and from this point all dimensions should be made; one other pier should be placed without the alignement as a scale of heights; this mark should be painted, in order that it may be easily distinguished.

By means of these fixed stations a work may be traced with facility and confidence.

Such are the preparatory operations for laying a foundation, when piles and a coffer-dam are employed. But there is another good means of establishing a foundation in water, by means of *caissons*, which may be employed when coffer-dams cannot, either in consequence of a great depth of water or great expense.

There are two kinds of *caissons;* one with a bottom in which the masonry may be constructed dry; the other without a bottom, and used for constructing rubblestone masonry. The first kind of caisson was invented in England and perfected in France; it was used with success in constructing the foundation for the bridges of Saumur and Tours, and afterwards at Toulon, and recently with the greatest success for constructing the new bridges at Paris.

This kind of caisson is a large flat-bottomed boat, the

bottom being horizontal and composed of jointed timbers; the sides are framed, planked, and caulked; and constructed in such a manner that the bottom may be detached from the body of the caisson.

The caisson when used should be fixed in the place where the masonry is to be placed, and maintained in its place by moorings and poles, in such a manner as to prevent its moving, except vertically. It is seldom that the natural bottom of the river presents a level surface upon which to place the caisson; generally these inequalities are removed by cutting off the higher points, or by filling up the deep places, by throwing in earth; a very delicate operation, requiring considerable skill and much practice. The bottom being prepared and caisson placed, the masonry may be commenced within it, or the caisson may be first filled with masonry and then placed upon the spot to be occupied, and sunk; of course, when the weight of the masonry is greater than that of an equal bulk of water, it will displace the water and sink.

As it is not always possible to make the bottom horizontal, and as it is not always necessary for solidity that the caisson should rest immediately on the river bottom, piers are frequently used for making a horizontal surface, piles may be first driven and then cut off at any required distance from the bottom by means of a saw worked under water. This ingenious machine was perfected by the late *M. de Cessart, Inspector General of Ponts et Chaussées*. At the present time a piece may be cut from a pier only two lines in thickness, at a depth of 15 feet.

It is preferable to fill up the deep places, instead of removing the elevations of the bottom. This operation requires considerable skill and ingenious expedients, such as were employed in fixing the foundations for the works at Dieppe and Tréport, by Lamblardie. All of which may be found in M. de Cessart's work, the details of which would lead us beyond our limits. In order to avoid the rising and falling of the caisson during the construction of the masonry, and more particularly where this is caused by the tides, some engineers have first loaded the caisson in order to sink it and fix it in its proper sit-

uation; others permit it to float until the masonry is constructed in the interior.

Each has its advantages and disadvantages, and the preference of one to the other must depend upon circumstances. When the caisson rests upon piers, all the openings between them should be filled with stone, and to preserve them in their places a row of jointed planks or piers should be driven around the foundation.

The first kind of caisson was used in constructing the foundations of the bridge *Des Arts* and of the *Jardin des Plantes*, also that of *Jena* opposite l' Ecole Militaire. By this means a great saving in time and expense is made over the common method of coffer-dams.

The second method without bottoms has been in use in Italy for a long time, particularly for maritime works. This method is very economical when we have a firm bottom to work upon.

The employment of this method, requires rubblestone mortar, which is indispensable in this kind of works. It was used with perfect success in forming the new pier at the bridge *Nôtre Dame de Cahors*, in 16 feet of water (French.)

The sides of the second species of caissons do not float, but are left adhering to the masonry; this, however, does not cause the binding row of piles and filling-in between the piers to be dispensed with. The rubble mortar is poured into the caisson by means of tunnels, in order that it may not spread in passing through the water. This method of laying a foundation offers many advantages, and at the same time presents some difficulties; the construction of works by this means, should be confided only to skilful and experienced engineers.

CHAPTER XX.

Construction of Arches.—Centres for large Arches.—Decentring.—Wooden Bridges.

The masonry of piers, abutments, and even the commencement of the arches, when of large span, of which we shall now speak, may be raised a certain height without much difficulty, but in a short time the inclination of the voussoirs will be such as to require a support.

Friction will sustain one body upon another, when polished, until the surfaces of contact make an angle of 18° 20′ with the horizon, but observation has shown that friction will support one voussoir upon another until the angle of inclination is 39° 4′; beyond this, the voussoirs must be supported. For this purpose a frame work is used, and is called a *centre;* the disposition and size of the pieces of which, should be such as to support the weight of the arch without giving. See *Plate* 4, *Fig*. 33.*

In the construction of small arches the centre is formed of two inclined rafters which at their highest extremities abut against a king-post placed in the lesser axis of the arch, and attached to it by means of shouldered tenons; the lower ends of these rafters are supported by projections in the abutments placed below the spring of the arch; they are sometimes supported by corbels; posts are then placed perpendicular to the rafters which support the curved pieces called *ribs;* a horizontal tie or binder, which embraces the king-post and rafters, binds the whole together.

The *ribs* should not be close to the intrados, a space of seven or eight inches should be left between them for the purpose of placing the pieces called *cushions;* these pieces are horizontal and perpendicular to the *ribs*, and are to receive the voussoirs immediately upon them.

Such is the common assemblage of carpentry used, and the composition of a *form*, several of which, compose a centre for an arch of a medium span.

The number of *forms* or ribs should evidently depend on the magnitude of the arch, and should be calculated in

* Fig. 33 represents the most approved English construction for a centre, and is much superior to the best French system. This centre was employed in the construction of Waterloo bridge at London.—Tr.

such a manner that the timber will not bend under the weight to be supported.*

Upon the centre properly disposed, the voussoirs are to be placed; which, for common arches, requires only ordinary care, but for large arches the greatest care is necessary for the success of the work.

As it is not possible to verify the exact position of the voussoirs by means of the radii of curvature when the centre or centres are at some distance, the position of each voussoir must be calculated, by determining the distances of the points of intersection of the radii of curvature with the horizontal diameter, from the perpendicular let fall from the circumference-extremities of the radii, likewise the ordinates to the same extremities. By means of these co-ordinates and the fixed marks upon the piers and abutments, it is easy to determine exactly, with long rules and levels, the position of each voussoir. The direction of the joints, normals to the curve, or the inclination of the voussoirs, is verified by means of a quadrant for this particular purpose, the limb of which is graduated for each voussoir.

The use of this instrument is very simple, one side of the quadrant is placed upon the face of the stone which is to form a joint, and a thread to which is attached a small weight is suspended from the apex of the triangle, or centre of the circle; this thread should cover the mark answering to this voussoir; if it does not, we may increase or decrease the inclination by means of wedges until it does. When in this position if it agrees with the co-ordinates we may be certain that it occupies its true position.

Independent of good materials, precision in execution, and the best of mortar, the success of the construction depends particularly on the kind of centre used.

* The relation between the weight of an arch stone and its pressure upon the centre, in a direction perpendicular to the curve of the centre, may be determined from the following equation; $W(\sin a - f \cos a) = P$. Where W is the weight of the arch stone, P the pressure upon the centre, f the friction, and a the angle which the plane of the lower joint of the arch stone makes with the horizon.—*Treadgold's Carpentry.*

The pressure of any number of arch stones upon a centre of equal weight may be found by the following equation: W (sum of cosines of $n\,a - f \times$ sum sines of $n\,a) = P$. For further particulars respecting centres, the student is referred to that excellent work on Carpentry, by Treadgold, published in 1820.—Tr.

Heretofore, centres have had a number of points of support on the ground. This disposition caused the middle of the rafters to support the weight, which is not advantageous for the resistance. The tenons and mortices which they require, weaken the wood. This system has very justly been renounced for the *cocked centre.* In this system the rafters are disposed in such a manner that the middle of one is supported by the end of another, and thus they form an assemblage of triangles, having rafters for their bases. The whole is connected together by ties in the direction of the radii of curvature; they embrace the end of one rafter and the middle of another. This disposition of pieces permits the whole to take a movement towards the keystone, and afterwards to sink under the weight, without danger to the stability of the work, when skilfully conducted.

To direct with success the construction of a large arch, it is essential to know the divers movements which take place in centres, as well as arches, at the time of construction and after.

Immediately after the centres are raised they sink under their weight, afterwards under the weight of the arch. The effect of these settlings should be anticipated, and the curve of the centre disposed accordingly.

As soon as we begin to place the *voussoirs* upon the back of the arch, their weight will cause the centre to rise towards the key.

This may be opposed by placing a heavy weight on the key. In proportion as the arch is raised the centre sinks; this new effect is owing to the weight of the *voussoirs.* At the moment the keystone of the bridge of Neuilly was placed, the settling was ($0^m.354$) about 14 inches.

From these divers movements in the system, there result, *first,* an opening in the superior part of the joints of the *voussoirs* at a short distance from the perpendicular raised from the spring of the arch, afterwards higher up; after the keystone has been placed these openings close again.

The total weight supported by each centre of the bridge of *Neuilly* was about 2,600,000 pounds. The settling under this weight continued from day to day until

the centres were removed. At this period the total sinking was ($0^m.52$) about 20 inches. In order to diminish the settlings of arches, it was formerly the custom to lay the last course of *voussoirs* dry, and force them together with wedges of wood. This method, however, might occasion the rupture of an arch, and consequently is vicious. This method has been renounced. The keys and centre keys should be laid in a full bed of good mortar. There is no fixed period for removing the centres with respect to the degree of solidity resulting from the acceleration or retardation of this time.

No difference has been discovered between the movements of an arch, the centre of which was removed immediately after the keystones were placed, and one where it was permitted to stand for some time to consolidate the mortar.

Prudence, however, requires that the centre should stand a short time, say 15 days, according to the porosity of the stone and the nature of the lime.

In proportion as the cushions are removed the centre necessarily rises.

The point of rupture of arches, which the experiments of Perronet has placed, in the most unfavorable case, at about one third of the distance from the spring to the key, proves that the cushions may be removed without danger up to this point, since in this part the centre is repelled towards the arch by the weight of the superior *voussoirs*.

The cushions should be slowly removed in order to prevent any part of the arch which might fall acquiring a great velocity; as that would cause the inevitable fall of the whole arch.

The cushions should be successively removed advancing towards the keystone; they should be removed symmetrically on both sides.

The removal of the cushions of the bridge of *Neuilly* occupied 19 days. The seven last courses were removed the last day. In proportion as the cushions of the above bridge were removed they were replaced by blocks of wood placed between the ribs and arch. All the cushions being removed these wedges were destroyed with the

chisel; this occupied about an hour; as the operation advanced towards the key, they broke of themselves under the weight of the arch, which took a uniform and successive settling.

When the ribs were free they rose ($0^m.16$) about 6 inches, owing to the elasticity of the wood.

During the time occupied in removing the cushions the arches settled ($0^m.162$) about 6 inches, and during the removal of the wedges about 1 inch, the next day after, the arches settled ($0^m.029$) about 10 lines; and continued to diminish, and finally ceased at about the time the roadway was made and finished. After the work was finished, the whole settling was found to be ($0^m.29$) 11½ inches.*

Such, in a few words, are the essential operations for the construction of large arches for bridges; and such are the principal effects resulting from the construction of the centre and the removal of the same, a knowledge of which is absolutely necessary to the engineer charged with the construction of this class of public works.

Bridges in Wood.

The various kinds of wooden bridges may be divided into two classes.

1st. Where the roadway rests upon a planking, established upon horizontal beams, whose extremities rest upon the soil when the bridge has a single opening, and upon piers when larger.

2d. This class is distinguished from the former by the bridge being composed of an assemblage of timber; the points of support are at the extremities of the arcs of circles or polygons, according to the apparent form of the centre. These are called *wooden spring arches.*

The first kind is applicable only to small openings or a small depth of water.

The second may be applied to large openings and great depth of water.

The opening is called a *bay;* the extreme points of support are called the same as in bridges of masonry, *abutments,* and the intermediate points are called *piers.*

* From the commencement of the decentrement.

Timber abutments are constructed in the same manner as stocades, as will hereafter be detailed.

Piers are simple or compound, according to the kind of bridge. A simple pier is merely a row of piers crowned or coped, with a large piece of timber called a *cap*, which is connected to each pier by a tenon and mortice. A compound pier is formed by placing several simple piers together, agreeably to any system previously adopted.

The points of support for the second class should be above the highest water.

Such an assemblage of timber forming the ribs and piers should be adopted, as will permit a defective piece to be replaced without injury to the rest.

In advance of piers, ice-breakers should be placed, isolated from the bridge.

It is customary to diminish the lengths of the sleepers or *string pieces*, by placing them on corbels, which project out from the face of the abutment or pier, from a yard to a yard and a half. Sometimes this saliency is supported by braces.

The platform upon which the earth is placed for the roadway is formed of jointed planks placed perpendicular to the string pieces.

Bridge pieces toothed on the string pieces, and placed at certain distances between the planks of the roadway, which they rise above, receive by tenon and mortice, the upright posts, and interior and exterior ties of the hand railings.

A plank should be placed vertically against the interior row of side-walk posts, and may be called the *curb plank;* it prevents the sand from falling upon the side-walk and at the same time supports the roadway.

Sometimes the flooring of this kind of bridges is covered with lead or copper, but this means of preservation is generally reserved for large bridges of the second class.

The square dimensions of timber with respect to the degree of solidity which it should possess, is determined in the first kind of bridges in the following manner :

1. From the law of resistance for square timber, which is, that the resistance is in the ratio of the square of the

dimension parallel to the power, multiplied by the other dimension; and in the inverse ratio of the length.

2. From the Havre experiments detailed, as we have before observed, in M. Girard's work on the resistance of solids, we may easily find the ratio of the deflection to the weight which produces it.

The effect of changes on horizontal pieces is important to be known. Buffon's numerous experiments giving the results of the absolute rupture, evidently will not answer for calculating the dimensions of timber for bridges.

It is known that a piece confined at its extremities is deflected only half as much as it would be if unconfined. It is also known that when the weight is distributed throughout the piece, it will support the double of what it would if loaded in the middle.

By means of these rules and experiments with a little experience, the dimensions of all the timber necessary for any construction may be determined.

Evidently these rules will also apply to pieces when inclined, since, as soon as the piece begins to bend when inclined, it may be considered as horizontal and the force acting perpendicular to the fibres, and thus the resistance be calculated by modifying, according to the degree of inclination, the absolute force wich acts against it.

These general principles are applicable to all kinds of wooden bridges, and with these we shall close the second part of our work.

[The translator intended to have added an article on *Iron Bridges*, but upon reflection found it impossible to do justice to the subject without extending "*The Course*" far beyond its original size.]

A COURSE

OF

CIVIL ENGINEERING.

PART III.

APPLICATIONS TO WORKS OF NAVIGATION AND RAIL ROADS.

CHAPTER XXI.

Natural and Artificial Navigation.—Explanation of the principal Works of Art.

DEFINITIONS.

Locks, are confined spaces of water, into which a boat may be floated, and when closed, by letting water in or out, the boat may be raised or lowered.

Tide Locks, are such as are used at the extremity of a canal, where the tide rises and falls.

Double Locks, are such as have several single locks jointed together.

Lock Falls, is the difference of level between the higher and lower surfaces of two reaches of a canal.

Tow Path, is the road upon which the horses travel, when towing the boats.

THE object of the third part of our "*Course*" is the application of the established principles of constructions to the works of navigation and rail roads; in this, is included the works of art, and the labor necessary for the melioration of navigation and conveyance. Navigation in general is *interior* or *exterior*, which comprehends communications by water, either by rivers or canals. Interior navigation is divided into natural and artificial. Natural navigation is such, as is carried on upon rivers and streams

which nature alone has rendered navigable. Artificial navigation is such as is prosecuted by means of rivers which art has rendered susceptible of it, or by means of canals.

Natural navigation is carried on upon rivers which have a sufficient depth of water to float boats, and when the slope is such as permits an ascending trade, either by means of sails, oars, or towing.*

The determination of the limit at which a natural navigation commences depends upon the following considerations.

1st. The draught of the boats used.

2d. Prevailing winds, with respect to the course of the river.

3d. The species of alluvion which floats in the stream, which of itself is the natural limit to the various parts.

4th. The breadth of the river.

The superior limit of the natural navigation of a river, is generally placed at that part of the stream where sand is floated, corresponding to a slope of about 3 yards in 6000. 1 in 2000.

This is the *maximum* of slope which admits of towing.

Oars and sails require a less slope, experiment has shown that it cannot exceed 1½ yards to 6000. This is the mean slope of the *Seine* between *Rouen* and *Paris*, and upon this it would be possible to carry on a trade, with respect to current, by means of sails and oars. 1 in 4000

The tow-path should be upon the deepest side of the river; there should be no obstacles between the path and bank of the stream. For the security and expedition of this operation in passing bridges, the tow-path should pass under the extreme arches when the arches are high, or the bridge of a single arch of large radius, as the bridge of *Louis* XV, or behind the abutments when the arches are low like *Neuilly;* carrying the path over a bridge must be particularly avoided.

The tow-path should be a little above the highest freshets. Upon rapid rivers, where the expense of towing is

* Steam might be added as another means of propelling boats, superior to any of the above mentioned, when there is water enough to float a boat of the necessary size.—Tr.

equal to that of ordinary transportation, it is evident navigation ceases to be advantageous; in which case this means of transportation is abandoned, as much on this account, as in consequence of the great danger of the navigation.

The Italians were the first who employed themselves with investigations concerning running waters.

Researches upon this theory, however important they may be for the determination of the regimen of rivers, cannot constitute a part of our "Course."

The principal obstacles to the natural navigation of rivers are, too great a slope, dams for manufactories, without the means which art furnishes for overcoming them, islands, and alluvions which wear away the banks.

The aid of art is required to overcome these obstacles; the works which are the means of surmounting these, constitute artificial navigation.

A level to determine the slope of the river is the first step towards the melioration of any navigation.

This operation requires many precautions in order to obtain the requisite precision for plans of this kind; the level should be made with the common spirit or air level.

To obtain this precision it is customary to divide the stream to be levelled into portions of about 1000 yards, when practicable, and to assume the middle of each division as the station, which should not be passed until we have verified it several times, the level is not sufficiently exact until the verifications correspond within 2 or 3 lines. If a river, which it is wished to render navigable, has sufficient breadth, is not subject to great alluvions and high freshets, and in every part presents the necessary depth of water with a moderate velocity, trade may be carried on upon it.

But if the natural slope is greater than 3 yards in height to 6000 in length, then the velocity of the stream must be changed by means of dams placed at convenient distances from each other.

In choosing the positions of these dams, and determining their heights, such a situation or height should be avoided as may injure the agriculture of the surrounding country during freshets.

Generally, these dams cannot be constructed without more or less injury to the proprietors of river lands, unless the river is confined between high banks, natural or artificial.

We have arrived at that point in our investigations which requires a few definitions, as indispensable for the understanding of this part of our work.

The *fall* of a dam is the difference of level between the superior and inferior levels.

The part of a canal between two contiguous locks is called a *reach.* Those works which serve to conduct water into a canal are called *feeders;* and those for supplying manufactories are called *sluices* or *canals.*

Those works of art employed in navigation for carrying boats over a fall occasioned by a dam, are,

Dams, Wiers, and Gate-sluices,
Simple sluices, and Chamber-locks.

These works furnish the means of opening or interrupting at pleasure the communication between the superior and inferior levels, and facilitate, more or less, the ascending and descending of boats. If these works are worked by means of gates either turning or sliding, with, or without a fall, it is a simple sluice or more properly half a lock.

If the stoppage is made by means of timber placed horizontally or vertically, the work is a dam.*

* Where bars exist in a navigation river, it is generally owing to the enlarged width of the channel, the natural remedy of which is to contract it, by which means the bottom will be corroded, and create more depth of water, or the height of water will be increased until a sufficient velocity be communicated to discharge the former quantity of water through the contracted channel; and it is evident, where the bottom is not liable to be corroded, that, if an excavation can be made through it by art, and the width contracted, the great velocity obtained will keep it open. But the increased velocity will not extend far down the river, consequently shoals will again form below, which must be removed in the same manner as before, and so on until the channel requires no more improvement.

Flashing. A more useful mode, in shallow streams, is to create an artificial flood for a time, by penning up the water in the river itself, or in side reservoirs, which may be opened when boats are passing. Where the trade is entirely descending this is far the best method and is used on the Lehigh river.

Wiers and Sluices. When the ascent to be overcome is greater, or the quantity of water which may be spared too small for the navigation in the open river, according to the above described modes, recourse is had to wiers for penning up the water below the fall or shallow, until it attain the level of the higher and navigable part of the river. This method is similar to chamber-locks upon canals.

In the *Machines Approuvées* may be found several methods for passing falls and rapids of rivers, which are very ingenious.—*New Edinburgh Encyclopedia,* vol. xxvii. See also *American Journal of Science, No.* xix.—Tr.

The Chamber-lock is composed of three parts; the superior gate, the inferior gate, and the chamber between; the chamber is to hold the boats.

By means of the gates, one reach may be isolated from another, and thus cause the water level to rise or fall; when this level is raised to such a height that the gate nearest the fall-reach will open, a boat may enter, and then if this gate is closed and the water let out into the lower reach to its level, the boat may pass into this latter reach; and thus, by a simple process, the level may be raised or depressed as may be required, and a boat thus passed from one reach to another.

The employment of sluices, wiers, or sluice-gates for overcoming a fall, present great difficulties and dangers of the worst kind for navigation, and consequently should be used with great caution.

The safety and facility of locks for this purpose should cause them to be employed in preference to all other methods, notwithstanding the increased expense which they occasion.

In forming an artificial navigation upon a river by means of locks, it is customary to place the axis of the lock parallel to the stream; this disposition, however, is vicious. When they are placed without the bed of the river with the axis perpendicular to the stream, they succeed much better and combine many advantages.

Islands in general are injurious to navigation because they augment the mean breadth of the mean section of the stream, and diminish the velocity and depth; the depth of rivers is always in the inverse ratio of their breadth. This defect is remedied by damming up the small branches and preserving the larger ones.

Natural bars formed at the mouths of rivers are inevitable consequences of the law of equilibrium, and art cannot prevent this action; this obstacle, however, may be overcome with the help of science, by constructing an artificial entrance or canal.

It appears that the Romans made use of this method at the mouth of the Rhone; for this purpose a canal was constructed, which has since filled up; vestiges of which,

however, remain at this day; it departed from *Arles* and communicated directly with the sea.

Without doubt this work led to the opening of the *Bouc canal,* which communicates with the Rhone a little below *Arles,* and terminates with the port of *Bouc.*

Dams well disposed for supporting the water at a constant height in all parts of the river, sufficient to float such boats as may navigate it, the effect of which is to moderate the velocity and reduce it to the uniform regimen of 1 yard to 6000 yards in length; commodious towing paths, chamber-locks for passing falls which are so disposed as to be free from alluvion; bringing into a single channel all the branches of a river formed by islands; finally, constructing a lateral canal to overcome such bars as may obstruct the mouths of rivers, are the principal and best methods of improving their navigation.

When the obstacles are such as cannot be surmounted by the above works, a canal must be formed without the bed of the river. But as this last work comes under the head of canals, which constitutes the particular subject of our following chapters, we shall defer going into the details of *this work* until we come to them.

CHAPTER XXII.

Canals in a Level Country.—Canals in a Mountainous Country.—Considerations on the formation of a Plan for a Canal on Uneven Ground.—Expense of Water.

Canals for navigation are divided into two classes.

1st. Canals in a level country.

2d. Canals in an uneven country, or having a summit level.*

The first are such canals as are constructed in a level country without locks other than *tide-locks;* many specimens of this class are to be found in Holland.

The second class constitutes such as connect two seas or rivers together or any two places, between which there are mountains or rising ground, as the Middlesex canal and

* The principal canals in the United States are of the second class.—Tr.

the grand canal of New York. The economy of transportation by means of navigation is too evident to require proof; the comparison, however, of this mode with that by means of carriages on a turnpike road, is so much in favor of the former that we are induced to give it.

A single horse may draw a boat loaded with 45 tons through a canal in 4 days when the space gone over is 104 English miles; a man is required to steer the boat; so that the transportation of 45 tons, 104 miles, by means of a canal, requires only 4 days' labor of a man, and 4 days' labor of one horse.

To transport the same weight by a road, for the same distance would require 352 days' labor of a horse, and 88 days' labor of a man to drive.

From which it appears that the economy of a canal over a road is the labor of a horse for 348 days, and 84 days' labor of one man for a single boat.

If we suppose that annually there passes through a canal 3000 boats, we shall find that for each year this canal makes a saving of about 1056000 days' labor of a horse and 252000 days' labor of a man; a result which merits great consideration.*

The works of art applicable to the two classes of canals being the same (in fact a canal of the first class may be considered a branch of one of the second), we shall confine ourselves to the latter.

The second class of canals was not known to the ancients.

Piercing mountains instead of passing over their tops where water cannot be obtained sufficient to fill the canal, is the most difficult case of canal making, and in general should be avoided, and employed *only*, when the engineer has found it impossible to pass the mountain with an open work. The result of the late discussion upon the *Saint Quintin* canal, which caused a large distance of tunnelling to be abandoned, is conformable to correct principles.

* The horses on the Grand Junction Canal travel 26 miles per day, and draw a boat containing 24 tons, exclusive of the boat, at the rate of 2½ miles per hour.—Tr.

Considerations on determining the Summit Level.

There are natural summit levels; two examples of which may be named, *Longpendu pond* and *Cony* near *Epinal*. The first, at its southern extremity empties into the *Bourbice*, which empties into the *Loire;* and at its northern extremity it empties into the *Heune*, which empties into the *Saone*. That of *Cony* empties its waters into the basin of *Moselle* through the *Niche* and into the *Saone* through the *Cony*. Ponds thus having two outlets, opposite and natural, without doubt first suggested the idea of constructing canals on similar localities. The first of these ponds has been employed to supply the *Charolais canal;* the second is the base upon which a plan has been formed for uniting the harbors of *Saone* and *Moselle* by means of a canal.

Evidently *chamber-locks* are necessary on the summit level. For this invention we are indebted to two Italian engineers whose names are unknown. They were first used upon the *Brenta* near *Viterbo* in 1481.*

Locks were first used in France on the *Briare* canal in 1605, more than a century after their invention.

All the locks constructed since their first invention, with the exception of the *Centre canal* which presents some useful improvements, are only imitations of the primitive one. Many improvements remain to be made in canal locks and other works for navigation. The best mode of treating this part of our subject will be to form a plan of a canal and lead the student through the different works belonging to it.

Details of the Course of Operations for forming a Plan of a Canal on the Summit Level.

Suppose it is wished to connect, by means of a canal, two navigable rivers, which are separated by a chain of high grounds or mountains, over which the canal must pass. The first operation will be to determine the lowest point of the intervening ground, and if there are streams

* By examining the works of the old writers on *Canals and Navigation*, it will be found that locks were constructed for Docks in Holland 100 years previous to their being used upon the Brenta. The first locks in Holland were invented and constructed by Jaussen, a carpenter of Rotterdam, and Corneli Muys of Delft. —Tr.

of water superior to this point, and if they can be conducted to the canal by means of feeders, likewise if circumstances of locality will permit the establishment of reservoirs which will contain sufficient water to supply the canal during the dry season.

Afterwards, it is necessary to determine by repeated observation under different circumstances, the mean quantity of water above the summit level; upon this point rests the practicability or impracticability of the canal; the supply must be calculated and compared with the expense.

The quantity of water required for the summit level is composed of several parts. *First*, the quantity lost by evaporation; by experiment this has been fixed as equal to a stratum of water about 34 inches thick per year. † The *second* is the expense by filtration, this in common earth is valued at half the evaporation. Inspector General Ducros observes that this is not enough, and fixes it at once and a half the evaporation. Fenwick says = twice.

This rule may generally be followed in common soils; but it is greatly augmented in sandy soils. An instance may be cited; the daily loss at the *Narbonne* canal, some time after its construction, was $\frac{1}{18}$ of the whole quantity of water in the canal in 24 hours. This expense, however, continued to decrease and finally ceased.

In order to determine the principal source of expense, that of working the locks, we must know the number of boats which will pass through them each year. The distances between the lock influences this expense. This part of the expense can be determined only, even by approximation, from ulterior considerations, into which we cannot enter at present.

If there are streams below the summit level, it is essential to profit by them; they should be examined with a view to bringing them into the canal to be used in locking below the summit level.

All the preparatory operations being made and the practicability of the canal determined, a plan of the ground or route of canal should be drawn.*

* As we have before stated, this should be on a scale of two inches to the mile for the plan; the ordinates of the profile should be six times the original scale—Tr.

† Fenwick says = 22 inches [illegible]

The direction of the line of the work should be determined from local considerations entirely.

Upon the supposed good direction, a longitudinal and transversal level is to be taken, to include double the breadth to be occupied by the canal, the levellings should embrace such superior streams as it is contemplated to bring into the canal.

This level should be referred to a plane above the highest point of ground on the route.

Upon the longitudinal profile of the ground the longitudinal profile of the contemplated work should be traced, also the position of the locks and their *falls*.

These preliminaries settled, the proposed plan should be examined in detail, the changes and rectifications which the slopes, as expressed by the transversal levels, may render necessary for the stability of the works, and expense of embankments; in fine, the dimensions of the various parts of the canal, the positions and nature of the divers works of art, of which the canal is composed, all of which should be determined from principles founded upon the functions which they are to perform.

We shall notice a few of these principles and apply them to a canal. In order to ascertain the distances between the various locks, it must be considered that these distances should be such, that a lock full of water taken from any one reach shall not interrupt the navigation, by lowering the water so much that a boat will not float until it is again filled; consequently, the minimum distance between two locks is the quotient resulting from the division of the cube of the lock, by the breadth of the reach between the two locks, multiplied by the height of water which can be drawn from the superior reach without injury to the navigation. This distance may be nothing in some cases, that is, local circumstances may induce us to suppress the reach altogether; in such cases the locks are called *contiguous* or *double locks*.

The reach, where boats generally stop, should be as long as possible, and when circumstances will permit, the canal in this part should have an increase in breadth, or, what is better, should be expanded into a basin.

The old opinion that each boat expended two locks

full of water from the summit level in going through the two branches of a canal is an error. We shall endeavor to show what this expense is *exactly*, in such a manner as to leave no doubt upon this point.

CHAPTER XXIII.

Continuation of the principles for forming a Plan of a Canal.—Researches on the Expense of Water.—Most advantageous Fall for Locks.—Best Form for Locks.—Applications.

In order to determine the exact expense of water occasioned by a boat passing through a lock, we must consider the mass of water filling the lock as composed of two prisms, one above the other; these prisms have for their bases the plan of the lock; their heights are different for different locks.

The first is called the *prism of floatation;* its height is equal to the height necessary for floating a boat. This height is often less than that which is generally preserved in the canal. The second or top prism is called the *fall prism* and its height is equal to the difference of level between the two consecutive reaches;* the prism of floatation is always found in single locks. This prism may be kept in double locks and drawn off as circumstances may require; but as economy of water is of great importance in working the locks, and there is some inconvenience in leaving this prism in double locks, it should be dispensed with. This consideration, caused it to be disregarded in the calculation of the expense of water.

In our researches we distinguish four cases of boats passing a lock at the summit level.

Supposing the locks to always have the prism of floatation of water in them:

For Separate Locks. 1st Case, two boats passing alternately or in contrary directions, they will each cause an expense of one *fall of water*. 2d Case, passing in succession, each boat causes an expense of *two falls*.

* That is, the difference of level between the water surfaces.—Tr.

"In estimating, I calculate the daily leakage of a well-made lock as equal to one lock-full of water", Smeaton.
He allows 4 locks-full for leakage, evaporation and other contingencies per 24 hours.

For Contiguous Locks. 3d Case, two boats passing alternately, each one spends as many falls as there are contiguous chambers. 4th Case, two boats passing one after the other, each one causes an expense of two floatation prisms.*

Such is the variable mode of estimating the expense of water from the summit level; we are indebted to the late Inspector General Gauthey for the light we possess upon this subject.

A little reflection upon the effects which result from the different directions in which the boats move upon the several suppositions, will convince every one of their correctness.

Inspector General Ducros has given several formulas for the expense of water according to the several cases named, more particularly where the locks are contiguous and when the prism of floatation is supposed to run out, which of course, increases the expense of water.

Inspector General Prony has generalized these formulas and extended them to the passage of several boats at the same time. Notwithstanding the correctness of these formulas they serve but imperfectly in practice, since the expense depends upon the order in which the boats pass, and it is not possible to anticipate this order.

It is reduced then to an approximation as near as possible; the advantage, however, should always be in favor of the canal; consequently, the most unfavorable case should be supposed, that is, where the boats pass successively through single locks, and for contiguous locks, alternately. *

Therefore, considering every expense of water, our resources should be capable of supplying the following:

1st. The quantity evaporated and filtrated.

2d. The quantity required for locking in the most unfavorable cases as above mentioned.

The most important consideration in establishing a canal is the economy of water, every possible means should be employed, and the most advantageous dispositions made, to prevent waste. With this view it is cus-

* This applies to the loss of water from the highest point or the summit level, it is supposed that there are feeders for the next locks below.—Tr.

"I generally reckon upon a lock-full for each boat the savings of water upon the aforesaid circumstances going in aid of the loss of water at the locks by leakage." Smeatons Reports. Vol I. 159p.

tomary to detain, during the dry season, the boats on the summit level, in order to cause them to pass alternately; it must be acknowledged, however, that this is injurious to the navigation and should be used with extreme circumspection for fear of abuses.

Our researches on the expense of water for passing boats through canals, show the disadvantage of *double locks*, particularly when near the summit level.

The *Briare canal* as well as the *Southern canal* is not exempt from this defect. The *Briare* canal near the summit level has seven contiguous locks. This disposition of locks should be adopted only when imperious necessity requires it.

The cause of their adoption undoubtedly was the apparent economy, because in two contiguous locks a saving of one pair of gates is made and part of the lock; by analyzing these inducements it will be found that the economy is nothing. From calculations made by General Gauthey, it is evident that the saving in favor of double locks is no more than one fifth or sixth.

Having determined the question with respect to the kind of lock to be used, we shall now proceed to determine the necessary fall to be given to locks.

It is evident that in case of double locks being used, if the falls were unequal, there would be an excess, or defect of water for the next lock; if an excess, it would be a dead loss; consequently, it should be a principle in contiguous locks to have equal falls.

This inconvenience diminishes when the locks are separate and fed by secondary waters.

The expense of water for lockage is counted by locks full; and in many cases a boat consumes only one lock full; evidently it is best for the expense of water to have as little fall as possible. Notwithstanding the advantages of equal falls, they are not to be used in all cases.

The best disposition is, to have small falls near the summit level where water is scarce, and to increase them as the water becomes more abundant. But if short falls save water, they increase the expense of construction.

Calculation will show an increase of expense of about

one third between the construction of two 4 feet fall locks and one of 8 feet fall.

If the branch of the canal does not receive secondary waters, the falls must be reduced proportionably to the losses by evaporation and filtrations, in order to reduce the water as near as possible to some uniform quantity. The most favorable case is, where these losses are supplied by auxiliary means; in the opposite case it must be acknowledged that the expedient of reducing the falls is not always sufficient, and we are liable to have the navigation stopped a good part of the year.

If the locality is such, that in forming a plan for a canal the two branches from the summit level cannot be watered except from the culminating reach, or if only one branch is favored with secondary water, then the lock-falls should be different.

In the first case, where each branch is watered from the summit level, the falls should be equal. Agreeably to the above considerations on evaporation and filtrations, which augment in proportion as the length increases, we should diminish the falls; this rule may be departed from in consequence of the advantages which result from equal falls.

In the second case, where one branch receives auxiliary waters, we should adopt short, but equal falls, near the summit level to the place, where the secondary water comes into the canal, from this point the falls may increase, because we have more water.

Such are the considerations which should guide an engineer in his choice of falls for locks and their situations with respect to the summit level.

Examination of the most advantageous Form to be given to Locks, and their size.

The size of locks evidently should depend upon the number of boats which they are intended to hold at one time; they are classed under two heads, the large and the small. The large locks, calculated to hold several boats at the same time, evidently occasion a greater loss of water than the small ones, in consequence of the spaces between the boats, necessary for their free movement. The large

locks do not give any advantage with respect to economy in time; experience has shown that five boats may be passed through a small lock in the same time that four boats can through a large lock.

A large lock requires a constant expense of water, whether the lock is filled with boats, or only a single one, and it may frequently happen that a single boat must be passed, thus occasioning a great loss of water.

The small locks for a single boat are preferable then, for the expense of water. This is the species of lock generally adopted; the large locks were adopted probably through motives of supposed economy in their construction.

This economy consisted in saving the general platform or paving of the whole lock when very large; an example of which, is the grand lock of *Slykens*.

When in the judgment of the engineer a navigation requires the large locks, he should connect with them small locks, with a general platform, for the passage of a single boat, as at Slykens and many other places in Holland.

If large locks are thought to be preferable on account of the economy, which will often be found illusive, they will (not) be found preferable in but few cases.

With respect to the *plan* or horizontal projection of the lock, some have preferred the elliptical form, (the utility of which, however, we cannot discover), probably with an idea that this form gave an additional resistance to the pressure of the earth; this pressure, however, is not sufficiently great to require any particular form to oppose it.

It is the pressure of water introduced behind the masonry which is to be particularly regarded; this consideration requires that the thickness should be such, as to insure stability independent of the resistance from appareil and elliptical form, which adds very little to the stability, because of the little curvature which must necessarily be given to the walls.

The elliptical form for locks augments the expense of water and construction, occasioned by the appariel which would be more expensive than for a right line wall.*

* Although the curved form for locks was renounced long since in England and France by all engineers of reputation, still this form has been adopted in the United States, even as late as the year 1824. 1. Upon a part of the Grand Canal. 2. Upon the Pennsylvania *Union Canal.*—Tr.

The above reasons should cause the curved form to be rejected and the right line one substituted for it. The *plan* should be a parallelogram, in length and breadth a little more than the boats used upon the canal.

Locks for a river may be of the large size; and also on canals, when the supply is abundant and the navigation carried on with large and small boats at the same time, as in Holland. In the case of large locks on canals, the locks should be divided into two parts by a pair of gates in the middle, and thus be able to pass large or small boats, which saves time and water.

This is the method in Holland where the canal is connected with a river, in which case the same boats can navigate both river and canal. In Flanders, where a large and small trade is carried on, two locks are used. The Bouzinga lock on the canal from Ypres to Nieuport presents some great advantages in saving water. The total fall is about 20 feet; and the engineer was obliged to adopt this as the fall of the lock; two lateral reservoirs were constructed, by means of which two thirds of the fall prism is saved, which reduces the whole expense to about that of a common lock.

This method is worthy of imitation when local circumstances oblige an engineer to adopt a great fall near the summit level.

When large locks are used upon rivers, the longitudinal axis, which is generally parallel to the direction of the current, may be more advantageously placed perpendicular to this direction. The two pairs of gates are in the bank of the river and separated from each other by the dam; the two gates have their planes in the same right line; the dam should be supported by a pier between the two pairs of gates. The first idea for this disposition which presents many advantages and obviates many of the objections inherent in river locks, is due to the late M. Gauthey, who first proposed it in his excellent *Mémoire* on canals and locks. This *Mémoire*, printed with those of the *Académie de Dijon* in 1783, has furnished the principal observations on canals with which we have enriched our "Course."

These large river-locks should have a breadth at least

double the length of the boats which navigate the river; this is necessary for the free passage of the boats.

When this kind of lock is used, the dam near the lock gates should be raised above the highest water; otherwise the water would run over the dam near the gate and injure the entrance into the lock; and without this precaution the current on the superior level might draw the boats over the dam.

The principal points in the project for a canal being determined as above, we may proceed to treat of the particular works belonging to a canal, which are,

Reservoirs—Feeders—Canal-proper, and Tow-path—Locks—Culverts—Waste-weirs—Aqueduct bridges—Bridges of Communication—Tunneling.

CHAPTER XXIV.

Reservoirs and Feeders.—Canal-proper considered as an Earthen Work.—Centre of Cutting.

Reservoirs are natural or artificial ponds, in which water may be collected and preserved for any intended purpose; their dimensions in length and breadth and depth, should be such as circumstances may require. The waters of a reservoir are supported by means of a dam across the valley in which the reservoir is placed. The most beautiful reservoir known is that of *St. Féréol*, which is intended to supply the *Languedoc* canal. The dam in the deepest part of the valley sustains a height of water of 112 feet. It contains near 7,000,000 cubic metres of water, more than enough to fill both branches of the canal.

The examination of the disposition and construction of this reservoir will furnish principles upon which to fix the projection and execution of similar works.

The dam in the deepest part is formed by three walls isolated from each other, and the spaces between them filled with earth, the principal wall being in the middle. The interior wall supports the earth which forms the in-

terior of the dam. This disposition requires two vaulted galleries which go through the whole extent of the walls.* By means of these galleries we reach the arched ways to manœuvre the sluice-gates which are placed in the lower part of the interior wall, and which serve to drain the reservoir when required. The first construction of the dam walls was defective from the foundation, but has since been remedied at considerable expense.

As much as we admire this magnificent work we cannot dissemble that great faults were committed in its construction and plan.

The principal fault, was the great confidence reposed in the use of clay for rendering the dam water-tight; a layer of this substance was placed against the interior slope of the dam. Experience has shown the insufficiency of this substance under a great pressure of water, and demonstrated conclusively, that impermeability under a great pressure of water cannot be obtained, except by means of masonry made with great care.

A single wall of sufficient thickness to support the water, and constructed of good materials in a careful manner is much better than a number of walls separated from each other; to repair which it is both difficult and expensive. For the common use of the canal, the water from the reservoir is supplied through two sliding gates; one of these gates is placed about two yards below the surface of the reservoir when full, and the other about eight yards below the same surface.

When the water is below these openings, three others near the bottom furnished with large pipes and stop-cocks are used; the last remains of the water may be carried off by means of a sluice-gate at the very bottom of the reservoir.

This is opened only when repairs to the dam are required, or to clean the reservoir.

The expense of water, when the reservoir is full, is regulated by two sliding gates at the upper surface, but when the water becomes low, and it is necessary to economize, the stop-cocks are used; they are constructed

* That is, from one end of the dam to the other.

in such a manner as to regulate very correctly the expense of water required.

A second reservoir was found necessary and constructed some years after the first, the *Lampy* reservoir, as it is called, in which the defects of the first were avoided. The dam of the *Lampy* reservoir is formed by a single wall sufficiently thick to resist a pressure of 50 feet of water. Notwithstanding the precautions taken in the construction, filtrations were apparent a short time after the work was finished, and were stopped by pouring a large quantity of quick lime into the reservoir. The particles of lime thus suspended were carried into the interstices and filled all the openings in the joints of the masonry, and even insinuated themselves into the pores of the stone, and thus have given it an impermeability essentially necessary for such works.

This method may be frequently employed, and the success of the above case proves that it may be employed with confidence.

Feeders.

Feeders, as their name expresses, are small canals for conducting water into a reservoir or canal.

The construction of feeders requires only excavation and embankment which may be executed in the ordinary manner, in earth or stone; sometimes tunneling is necessary and galleries even. We have already given a caution against the use of tunnels; they should be avoided by carrying the work round a hill instead of through it. A tunnel for a feeder presents the same difficulties as for a canal. The slope of feeders is different for different canals.

The slope of the *St. Féréol* feeder is about 2 feet 10 inches to 1083 yards; the slope of the *Courpalette* feeder to the *Orleans* canal is only 2½ inches to 1083 yards. The slope of the latter, was determined from experiments made by the late *M. Chézy*, consequently the correctness of it may be relied upon.

This slope appears to be the least which can be adopted for a feeder. This slope should be employed when the locality does not permit of the establishment of reservoirs

much above the summit level; when a larger slope can be employed, it would be well to use that of the *St. Féréol* feeder.

Drains and waste-weirs should be placed in feeders, in order to command the water, and take from the streams or reservoirs, only as much as may be wanted. These works also will serve to free the feeder from water when repairs are necessary.

Feeders should be so disposed as to be free from freshets, particularly if used for feeding Canals.

Canal-proper and Tow-path.

In dry soil the bottom of a canal should have a slight slope, that is, the part of the canal between two locks; there are some advantages in a small slope, it facilitates the draining of the reach and diminishes the lock-falls.

In marshy ground it is essentially necessary to give a slope of about 1 to 1½ inches per mile. 1 in 63,360 ∴ 42,240

The breadth of the canal at the bottom depends upon the breadth of the boats by which it is to be navigated, at least it should be three times the breadth of the boat.

The sides of a canal have a slope generally, the base of which is about twice the height.* The determination of the base of this slope depends upon the nature of the soil and kind of construction, whether it is to be covered with stone or facines; in case of the latter, a base of once and a half or even once the height is sufficient; the sides may be left in earth. When only one tow-path is employed, it should be placed about a yard above the level of the water, and should be on the side nearest to the source of the prevailing wind, otherwise the action of towing together with the wind would cause the boat to drive against the sides of the canal.

The tow-path, if for horses, should be made in the same manner as a common road, about 10 feet wide.

When a canal passes near the bank of a river liable to frequent freshets, the canal on the side next to the river should have a banquet or dyke to protect it from the

* Mr. Strickland says, the slope adopted in England is two feet perpendicular to three of horizontal measurement. He also says, the towing-path should be from eighteen inches to two feet above the water level.—Tr.

highest freshets; the foot of the slope of this dyke should be fortified with stone.

Embankments for a canal should always be made of fresh earth when to be obtained; for the want of this, if made of light earth, a mass of clay or puddling stuff should be placed in the middle of the embankment.

The solidity and impermeability which this kind of work should have, requires great precautions in the construction; the sod should be removed from the earth upon which the embankment is raised in order to promote adhesion; the embankment should be raised in layers of 5 or 6 inches in thickness and well rammed. The water should not be let into the canal until some time after its completion, and only in parts, by means of dams across the canal. These precautions are necessary in order to facilitate repairs which will be needed in consequence of filtrations, and in anticipation of *slips*, or a movement of the bank of the canal, which frequently occur at this stage of the work, and when in embankment the whole water in the pond would overflow the surrounding country.

Plantations of trees along the banks of a canal are both useful and ornamental; they should not be planted too near the canal, as their roots will cause leaks.

Parallel to the canal and at some distance from the foot of the exterior slope of the embankments, ditches should be established for carrying off the superabundant water from the canal.

It is evident that in cutting canals no more excavation is required than that necessary to hold the water at the given depth and breadth; according to the modern practice a bank is raised on both sides, from the excavated stuff; it is evident that if the banks are made of sufficient closeness and strength to hold water, the water surface of the canal may thereby be raised above the natural surface of the ground, and thus the greater part of the excavation saved.

One of the first objects, therefore, in canal cutting is to know at what height above the surface of the soil, the canal may be carried on level ground, when the excavated stuff will just make the banks. This case is called *level cutting*.

When the ground along which the canal is to be carried, has a declivity perpendicular to the canal, the quantity of stuff required for one bank is greater than for the other; this disparity may increase until one bank vanishes and only the lower bank is required. This is the simplest case of canal cutting and admits of being laid out in a more simple manner than has been heretofore employed, as we shall soon show; this case is called *oblique cutting;* the slope of the excavated part of the canal is supposed equal to the exterior slope of the embankment; now there is a certain point in the section through which, if any line be drawn representing the surface of the ground, which line we will call the line of cutting, the portion of the section exhibited as embankment will always be equal to that shown as excavation. We shall call this point the *centre of cutting.*

PROBLEM.

Given the Profile of a Canal in sidelong Ground, with Parallel Slopes; to find the Centre of Cutting.

Let $ABCD$ (*Plate IV, Fig.* 34) be the profile of a canal, $CDEGF$ a section of the ground. Produce the lines BC and ED to G and A. Draw the perpendicular $C\,m$, $D\,n$, and the diagonals AG and $m\,n$ intersecting in p.

Through p draw the parallel $s\,p\,t$, and bisect it in o, and o is the centre of cutting; through which if any line $H\,o\,F$ be drawn cutting the slopes AB and EG produced, the section $HBCw$ will always be equal to $wDEF$.

$D\,m\,n = C\,D\,n$ consequently $m\,n\,GE = CDEG$. But $m\,n\,G\,E = s\,B\,G\,t = CDEG$, and taking away $C\,v\,t\,G$ we have $s\,B\,C\,v = v\,D\,E\,t$, and the triangles $H\,s\,o$ and $o\,t\,F$ are equal, having equal angles and one side common. The sum $H\,s\,o + s\,B\,C\,v = o\,t\,F + v\,D\,E\,t$, consequently $HBCw = wDEF$.

Cor. 1. The centre of cutting is also the centre of cut and cover, because $H\,o$ is always equal to $o\,F$. Hence if a line be staked out on the ground at the level of the centre of cutting, it will exhibit the middle of the space required for the use of the canal, whatever may be the

slope of the ground, provided it be regular as far as the breadth extends; the distance on each side $H\,o$ or o F of the centre may easily be found by a line drawn across the section, with the given inclination of the ground.

Cor. 2. The distance of the centre of cutting from the centre of the canal at water surface, is constant, and is equal to $u\,q + D\,E$. Hence if the line of the middle of the cut and cover be laid out, or the centre of cutting and a row of stakes placed at certain horizontal distances therefrom, and the top of these stakes be made even with the level of the surface water, they then will exhibit the line of the middle of the canal when finished.

Cor. 3. At half the distance of the general breadth *AE* from the centre of cutting, and on the same level, is a point in the exterior slope of the bank; and a line of stakes may be placed at that distance and level, which will direct the wheeling of stuff for forming the bank. At these stakes a level and plumb-line may be applied, together with the slope of the bank, by which the point *F*, where the exterior slope of the bank meets the surface of the soil will be found and may be marked, and the edge of the excavation will be at an equal distance on the other side of the centre of cutting.

Cor. 4. The horizontal distance $o\,v$, of the inner slope of the bank, from the centre o is constant and will be found by the following proportion; $D\,m : m\,C :: z\,o : ov$; a line of stakes may, therefore, be placed at this distance to direct the wheeling as in *Cor.* 3, and by means of a level and plumb, the commencement of the bank and excavation may be laid out.

Many other problems might be given, but we have confined ourselves to the above general case, and refer the student to the *New Edinburgh Encyclopedia*, vol. xiv, from which the above is extracted.

In order that a boat may move on a Canal [illegible]

CHAPTER XXV.

Chamber Locks.—Determination of the Form and Dimensions of the various Parts of the Lock Head.—Details upon Lock Heads.—Method of introducing the Water into a Lock.—Lock Gates.

Locks.

We have already given the length and form of lock chambers. It now remains to give the works belonging to a lock, and to fix the dimensions of the lock heads.

It is evident that the dimensions of the divers parts of the head work of a lock should correspond with the resistance which they are to oppose to pressure.

In *Plan*, the upper and lower head works are the same for the parts which are common; as the dimensions of the recesses for the gates, the wing or return walls, and the breadth of the gates are the same; they differ only in the parts outside of the gates which are so arranged as to facilitate the working of the gates.

Above the head gate there should be sufficient space for placing grooves for the stop planks, by means of which we may form a dam, which is frequently necessary for repairing the chamber.

The recesses which come next in order, evidently should be as long as the gate is wide in order to receive it when open; and to this should be added sufficient space for the play of the gate. It is in this part that are placed the hollow-quoins, which are semicircular spaces for the head posts of the gates to play in; a gudgeon is placed in this groove for the head post to turn upon. The mitre-sill (which is formed of two pieces of wood, making a certain angle with each other, and against which the gates shut) terminates this lock head.

The length of the part on the lower side of the gates is not the same for both gates; it depends upon the purpose to be answered thereby. In the upper gate this part joins the head to the chamber, and its length depends upon the thickness necessary for the breast wall, because, with respect to the play of the gate, this distance may be nothing; but when this wall is vertical and not high, the same length may be given it as the distance from the

grooves above the gate, to the gate, for symmetry of form.

At the lower gate, as this part terminates the lock, its length should be sufficient for the play of the same. The length of this part then depends upon the length of the balance beam. In France this length is fixed at ($4^m.70$) 15 feet, 3 inches.

With respect to the wing walls, which sustain the earth at each extremity of the lock and facilitate the entrance thereto, they should be established upon the diagonal of a square which has from 6 to 9 feet on a side.*

Combining together these different parts of a lock, the form and dimensions of which have been determined, we have the plan of a lock. (*Plate* V, *Fig*. 36).

The thickness of the *side walls* should be made to resist the pressure of *water*. The head of the upper gate, and the return wall of the same should be calculated to resist the pressure of *earth;* and those of the lower gate to resist the pressure of *water*.

The resistance of side walls should be against water for this reason, that a small quantity of water may be introduced behind the wall, between it and the earth; in which case when the lock is empty the wall must support a pressure due to the height of this water.

The ratio of the specific gravities of water and masonry should also be taken into consideration; generally they are taken in the ratio of 7 to 12. This ratio varies, according to the different kinds of material, as there is a great difference in the weight of different kinds of building stone. It will be necessary for the engineer to determine this ratio by experiments previously to using them.

It was formerly the custom to construct counterforts behind the lock walls; this method produces a little saving in masonry, which, however, should yield to more considerable advantages which will result from distributing the counterforts throughout the wall, thus increasing their thickness in order to resist filtrations more effectually. The thickness of lock walls should be diminished upon the interior of the wall, and gradually from the bottom to the top by retreats.

* We think it better to give the wing walls the form of an horizontal arch, of an agreeable curve with a slight inclination or *batter*.—Tr.

The coping of the lock walls should be elevated about 18 inches above the water surface when the lock is full.

The bottom of locks in Holland and Flanders is generally partly in masonry and partly in carpentry, but this method is vicious and should be avoided, particularly when we have other materials at our disposal.

Where building stone is to be obtained of a good quality, the bottom should be entirely in masonry; its shape should be either flat or in the form of an inverted arch. This in particular should be the construction of the parts near the gates; the bottom of the chamber may be in cut, picked, or rough stone, but should have the shape of an inverted arch. When the soil is bad, upon which a lock is to be constructed it should be encaissed, that is, a platform of masonry should be constructed forming a general foundation. This method is preferable to forming a foundation upon piles.

The fall walls are generally vertical in profile and a segment of a circle in the plan. In profile they may have the form of the curve of equal descent, which has the advantage of giving a horizontal motion to the water at the bottom of the wall; this form, however, has disadvantages in the shapes of the stones, which are very complicated. Finally, it is best to give it the first mentioned disposition. In all cases the top course of the fall-wall should be rounded on the exterior edge in order to reduce the action of the water; this course should also be shaped to receive the mitre-sill. That part of the platform or bottom which is called the *mitre-sill* or *heurtoir* has an angular form in the horizontal plane, the angle of which should be towards the superior reach of the canal; by this disposition, when the gates are shut they rest against each other and thus support the pressure of the water. It might be supposed, that, if the two sills made an angle of 90° with each other, the pressure, transmitted from one gate against the other, would act against the other perpendicularly to the fibres of the wood, and thus obtain the *maximum* of resistance; but this angle gives the gates the *maximum* of breadth and consequently augments the pressure of the water against them.

If the angle should be reduced to zero the gates would

no longer support each other, and although in this case we expose the *minimum* of surface, we destroy entirely their reciprocal support. Consequently, there is a *maximum* of advantage to be found between these two extremes.

Researches to obtain the most advantageous angle for these sills, have engaged the attention of engineers for some time.

Whatever may be the difference between the various solutions to this problem, resulting from a diversity of opinion with respect to the given parts, which, up to the present time, has not been completely solved, they all range between 109° 28′ and 143° 8′. From the experience acquired in the construction, of 26 locks with complete success, the mean saliency should be between one third and one fourth of the breadth of the gates. The angle adopted for the locks of the *Bourgogne canal* is 143° 8′, corresponding to a saliency of one sixth of the breadth of the gates. X

The latter method of determining this angle diminishes the breadth of the gates, which is an important consideration. Pieces of wood should be placed against the mitre-sills when of masonry, called *heurtoirs*. These *heurtoirs* prevent the gates from knocking off the edges of the voussoirs, forming the mitre-sills. Besides the gates shut closer against wood than against stone. In order to obtain this effect more completely, a layer of thick cloth should be interposed between the *heurtoir* and mitre-sill closely compressed by nut screws fixing it to the sills.

When the soil upon which a gate is established is bad, it is customary to drive a row of pile planks across the canal perpendicular to the axis, under the platform and immediately under the mitre-sill to prevent leaks, an action which would inevitably take place if the foundation was laid upon a grillage, the beams and sleepers of which would conduct the water.

Constructing the bottom of a lock in the form of an inverted arch evidently dispenses with the necessity of giving it the same thickness as the side walls, although it

X The greatest strength will be attained when the saliency is = 1/4 of the breadth of the lock, corresponding to an angle of 120° between the gates.

Renwicks Mech.s 448.p.

should oppose a greater resistance to the pressure of the water.*

The nature of the soil upon which the gate is established has some influence upon this thickness, which should vary accordingly.

On a firm argillaceous soil, the bottom should be from 4 feet 3 inches to 5 feet 4 inches† in thickness for a common-sized canal. This dimension depends essentially, however, upon the quality of the materials and particularly on the cement or mortar.

The bottom or platform for the lower gate generally, has a greater thickness than the upper one, because this part of the lock has to support a greater pressure than the upper gate. Frequently this part has a thickness of 6 feet,

These dimensions are far from being fixed rules, however, for this part of a lock.

Methods of introducing the Water into Locks.

The most simple method of introducing water into a lock is by means of a sliding gate or valve in the lock gate; this method has some objections; among which is the injurious effect produced by the water falling upon the bottom, and against the side walls; in addition to the fall, the direction of the current is of some importance, which is oblique to the axis of the chamber when but one gate is opened.

Another method is by means of crooked culverts or paddles, constructed in the side walls, which form a communication between the superior pound and lock, or between this and the inferior pound; but besides the bad direction to the current, which in this case is much greater than with sliding gates, there is the additional one of a great increase in thickness of the side walls, and these culverts require great care in their construction, and frequent repairs.

The objections to these two methods caused the syphon to be applied to this purpose, by the late *Inspector Gen-*

* Mr. Strickland, in his *Reports*, says, that one of the largest and most beautiful lock chambers in England is constructed with an inverted arch; the side walls batter into the arch at the water line; it is built upon piles and a log bottom of brick with a stone coping.—Tr.

† These dimensions are evidently too large, from one to three feet is sufficient.—Tr.

eral Gauthey; by this method the water is introduced into the lock over the walls, which for this purpose are arched.

The syphon removes the objections on account of falls and currents produced by sliding gates and culverts, but their construction is difficult. This method, however, has been executed with success upon the *Centre* and *Charolais* canals, according to the plan of *General Gauthey.* The success undoubtedly was owing to the great care taken in their construction.*

Details on the Construction of Locks and their Accessories.

The construction of locks requires the greatest attention in the choice of materials, and particular care in the use of them.

When practicable, without too great an increase of expense, locks should be constructed entirely of cut stone of the hardest kind, and one which the water will not affect either in a liquid or solid state. For the want of stone of a good quality, bricks may be used with success; but in this case, it is necessary that the angles, mitre-sills, coping, and in fact all those parts which are exposed to shocks and friction should be of stone.

In order to obtain impermeability for masonry, constantly exposed to the effects of a great pressure of water, a layer of rubblestone mortar may be interposed between the masonry and earth.

Care in the construction is not sufficient to insure solidity to a canal lock; it is necessary to prevent the water soaking through the work and softening the earth under it, which will be particularly the case at the extremities of the lock floor or platform.

The only method to prevent this is to construct a platform without gates. (*See Plate* V, *Fig.* 36, *h* and *k*).

This exterior platform is generally in wood, and is generally a grillage upon piles, the spaces between which are filled with clay or rubblestone mortar; the whole is covered with plank.

* Sliding gates should be opened and shut by a rack and pinion. The most approved valve in England, says Mr. Strickland, is one formed of two openings one above the other, about one foot high by two feet wide; the valve-covers are connected together, so that moving the connecting rod one foot vertically, makes an opening of two feet in water way.—Tr.

A particular kind of lock is necessary at the termination of a canal, when this termination is in a river liable to freshets or tides. This lock should be so constructed as to enable boats to enter the canal, whether the river is above or below the canal level; for this purpose tide gates should be placed in both extremities of the lock, the gates opening in contrary directions, the exterior one having the point of its mitre-sill towards the river; by means of such a lock, a boat may enter the canal in any stage of water, since by the mode in which they are worked they empty the lock into the adjacent reach and thus establish a communication between river and canal.*

An example of this species of canal is to be found at the new entrance of the *Languedoc* canal into the *Garonne.*

Gates.

The carpentry of a lock gate is a rectangular frame, with intermediate tie-pieces, and several braces.

The two posts forming the sides of the frame, one of which fits into the quoin in which the gate turns, is called the *head post,* and the other, which should be chamfered, is called the *mitre post.*

The principal brace or diagonal of the frame is used for the purpose of throwing the weight as much as possible upon the head post.

It is injurious to multiply the braces beyond a certain extent. Every brace which is placed below the principal diagonal brace, and which does not abut against the head post, is useless and should be suppressed.

The braces and cross pieces should not be flush with the frame on the side of the greatest pressure, by the thickness of the plank or boards, which should be let into the frame, and always should be on the side exposed to the greatest pressure. As the weight of the gates is considerable, and during their movement they are unsupported, as much of this weight should be thrown upon the head post as possible, by the arrangement of the timber composing it. In consequence of this consideration, the planking should be diagonal and parallel to the braces.

* *Fig.* 42, *Plate* VI, shows the plan and section of a tide lock at the lower or river gate; this is copied from Mr. Strickland's *Reports.*—Tr.

The paddles for introducing water into a lock, when of the sliding kind, should be near the bottom, in a frame placed in the gates.

From an examination of the dimensions and positions of the cross pieces and braces, there result two systems of construction for gates.

1st. By placing the cross pieces at equal distances from each other, having unequal dimensions, depending on the pressure which they should sustain.

2d. By giving the cross pieces equal dimensions, and placing them at unequal distances from each other.

Of these two methods, which give the same result with respect to strength, the latter is preferable on account of the equal dimensions of the timber.

It is customary to strengthen the whole system by iron cleats crossing the joints, placed on both sides and secured by screws with nuts.

The rotary movement is given to the gate on the head post, the lower extremity of which fits into a gudgeon placed in the bottom stone.

The gate is maintained in its vertical position by means of strong iron straps which go round the head post and are fastened to the coping.

The greatest care is necessary to render the gates tight, which will not be the case if the head post does not fit closely into the quoin. This precision depends essentially upon the centres of the gudgeon and collar being in the same vertical line in all positions of the gate.

Inspector General Gauthey has introduced a modification of this method, in order to diminish the friction, which has been used on the *Burgundy* canal. This improvement consists in fixing an iron trunnion in the axis of the head post which fits into a gudgeon at the top instead of the collar; this disposition evidently diminishes the friction. In order to preserve the gates they should be covered with a composition of tar and oil.

The gates of a lock are worked by means of balance beams fixed to the two posts of each gate. These beams should be placed at about breast-height above the top of the walls of the lock. This commodious and simple method requires but little power to open the gates, when

well balanced. The balance beam should be twice as long as the gate is wide, and in order to augment the counter weight the detached end may be loaded with iron or lead. Balance beams are used for working canal gates, but for large gates in sea-ports, as tide gates, this operation is performed by means of a capstan or windlas, and other means, according to the power required.

Paddles or sliding gates are raised and lowered by means of a screw, or a rack and pinion turned by a crank handle.

In whatever manner this operation may be performed, the power produced should always be proportional to the force required, which depends on the weight of the gate, friction, and the pressure produced by the height of water.

CHAPTER XXVI.

Culverts—Drains and Waste-Weirs—Bridges of communication, fixed and movable.—Tunnelling for Canals and Feeders.—Small navigation.

Culverts.

Culverts are works used for carrying off such water as it is not proper for a canal to receive; they serve to isolate the canal from streams which are injurious to its free navigation. Works of this kind may be divided into three classes, depending upon their position with respect to the level of the water.

1st. Culverts proper, are such as are under the canal, the canal passing over them, and when the bottom of the culvert is in the same plane with the bottom of the stream, the water having the natural slope of the bed.

2d. Syphon culverts, (or broken backed culverts) are such as change their direction from a level, by passing down one side of the canal and up on the other into the counter ditch, the bottom of these ditches as well as the streams being above the bottom of the canal.

3d. Aqueduct bridges, are such works as are used for carrying a canal over a stream or deep ravine, or a stream over a canal without stopping the navigation of the river.

The dimensions of a culvert evidently depend upon the quantity of water to pass through it in a given time. When the canal is to be carried over a considerable stream, the surface of which is in the same plane with that of the canal, which is the most unfavorable case possible, the stream must be admitted into the canal; when art is required to prevent alluvial deposits which is almost a necessary consequence of this construction.

There is a commendable example of what genius may accomplish under such circumstances; it is the manner in which deposits from the torrent of *Libron* on the *Languedoc* canal are prevented; the canal receives this torrent into its course; the situation prevented the use of the culvert or aqueduct. For this purpose a rectangular decked vessel is placed across the torrent during freshets. The disposition of this boat is such that it separates the stream of the torrent from the canal; when it is properly placed across the stream it is filled with water and sinks until the deck comes into the same plane with the surface of the stream, the sides and ends of this vessel rise some distance above the deck; when the vessel is placed across the stream, the sides are let down, by means of hinges, upon the surface of the stream, the ends remain vertical, their height being such as to rise above the canal surface, in consequence of which the stream and the floating alluvial matter, passes between without mixing with the canal waters.

The invariable position of this boat is preserved by means of two walls, one on each side of the entrance of the torrent into the canal, a little divergency towards the stream prevents the boat leaving its position.* As soon as the flood has passed, this vessel is cleared of water and removed to a place prepared for it in one side of the canal.

The culvert proper, as well as the broken backed culvert may be made in wood, and are then called *nozles*.

The details for constructing aqueduct bridges as well as *canal bridges* are the same as we have already given for stone bridges, except that these are to hold water, and

* This is the method employed for shutting the *London* docks, only the bow, stern, and keel of the vessel, fit into grooves constructed for this purpose. At high water when the dock is full, the vessel is floated into her position over the grooves, the water is then let into her hold, she fills, sinks and completely shuts the dock.—Tr.

the *canal bridge* must have a tow-path, if of considerable length; in general they should only admit boats in one direction at a time.

The most advantageous position for such works should be sought with the greatest care.

Drains and Waste-Weirs.

These are works used for removing the superfluous waters of a canal, occasioned by heavy rains or other causes which evidently endanger the canal banks, over which the water should never be permitted to flow. These works are also employed to drain the reaches of the canal in case of repairs being required.

The waste-weir carries off the superfluous water above what is required for navigation, and the drain empties the reach entirely. In consequence of the velocity due to the height of the water, the latter work will empty the canal in a short time.

Waste-weirs, from their use, are formed of only two side walls and a stone or plank bottom. The ends of the walls coinciding with the interior and exterior slopes of the canal bank; the bottom should have a slight inclination to the exterior of the bank and be in the plane with the highest surface required for navigation.

The fall of the water which passes through the weir should be broken (when the weir is above the natural surface of the soil) by a platform, upon which it should fall and pass into the counter ditch; a bridge should be placed over the weir. The number and dimensions of these works should be determined by the quantity of water to be carried off, in order to keep the canal water at its proper height.

The drains which are placed at the bottom, are simple sluices shut by means of sliding gates; they are formed of two side walls and a stone or wooden bottom, which should extend to the counter-ditch. In addition to the great expense, these works require considerable attention from the lock-keeper to work them; therefore, no more should be made than are absolutely necessary for the purposes intended.

The *syphon waste-weir*, which serves for both a drain and a weir, was invented by *M. Garipuy* and applied on the *Languedoc* canal.

This weir in certain cases will perform the functions of a common weir, and afterwards may be made a drain when required.

This weir is constructed in masonry, and consists of two unequal arms connected by a curve, the shorter opening into the canal and the longer into the counter ditch.

The action of this syphon is produced by an opening from the canal into the short arm about four inches below the common water level; the highest point of the lower surface of the curved part of the syphon should be nearly the same distance above the same level, in order that when the water rises to that height above the common surface, it may be discharged through the syphon acting as a waste-weir; as long as the water continues above the highest point of the syphon it will be discharged in this manner, and if the vent hole is stopped it will continue to discharge until the level of the water is below the opening into this arm of the syphon, agreeably to a well known hydrostatic principle.

The physical phenomena of intermitting fountains undoubtedly led to the application of the syphon for waste-weirs, as they depend upon the same principle.

All these works, with the exception of the syphon, which requires great care, present no difficulties not common to similar works in water. A good appareil, careful construction, and the precaution of puddling to render them water tight, are the principal precautions to insure success.

Aqueduct Bridges and Canal Bridges.

As we have before said, these are such works as serve to carry a canal over a river or ravine, or the reverse.

The dimensions of these works should always be determined by the magnitude of the navigation, and the quantity of water which should pass through them; these

works are constructed upon the same principles as a stone bridge.*

Communication Bridges.

Bridges are constructed across canals for public roads, and to connect the two parts of a plantation which a canal divides; if the canal is navigated by means of sails these bridges should be movable.

Among the many kinds of movable bridges, those most in use are the draw bridge, and the turning or rolling bridge. Local considerations, together with the manner in which the boats are propelled, should influence the choice of the kind of bridge. Whatever kind of bridge may be used, its dimensions should be such as are strictly required. Bridges over a canal should always be elevated above the tow path sufficiently to permit the horses to pass freely.

When movable bridges are used, the power required to move them should be determined from calculation, in order to adjust the power to the weight to be raised. The elementary principles of statics are applicable to this kind of problems.

Tunnelling.

We have already noticed the evils of this mode of establishing a canal or part of one; sometimes it becomes absolutely necessary, however, in which case the greatest care is necessary in blasting rocks in consequence of the fissures which explosions will cause, from which filtrations will inevitably follow. The excavation may be made with the pick, if the soil is soft and cohesive, which is the most favorable case for tunnelling.

The difficulties are greatly augmented when the soil is sandy, gravelly, or composed of a soft calcareous rock, or any other substance not possessing adhesion, and require the utmost attention of the engineer; in which case an arch must be turned, which augments the expense greatly.

When a tunnel of any great length is required, economy should induce a reduction in breadth; the breadth should

* For some practical remarks on the construction of Aqueducts, Culverts, and Tunnels, consult Mr. Strickland's superb work entitled, *Reports*, &c.—Tr.

permit boats to pass in only one direction; but recesses should be constructed in the sides at certain distances to permit boats to pass each other, at such places. It should be observed, however, that this reduction in the breadth of a canal or feeder augments the velocity of the current, and consequently retards the navigation in one direction.

The arch of a tunnel should be sufficiently high to admit a loaded boat with its tow mast erect. Light is admitted into these subterranean passages by means of tunnel-pits, or wells dug from the surface down to the tunnel.

These tunnel-pits also enable us to remove what is dug out, without the trouble of transporting it the whole length of the tunnel. When it is required to carry a canal across a mountain not very high and steep, the quantity of tunnelling may be reduced by *deep-cuts* on each side of the crest, which may be extended until the expense of excavation exceeds the expense of a tunnel.

The inconveniences resulting from *deep-cuts* in consequence of steep banks may be obviated by constructing a banquet and ditch for collecting filtrations and rain water, which injure the banks very much.*

We shall conclude our details on canals by a short notice of what is called *small navigation.*

System of Small Navigation.

This system presents many advantages as respects economy in water, and expense of construction, and in

* When an engineer has determined to make use of *deep-cuts* instead of tunnels or locks, the site is to be carefully examined to determine if the ground will be liable to a *slip*, as on this depends the slopes to be given to the cuts; the removing of the earth from deep-cuts is of considerable importance.

The principal methods are, wheeling planks, in an oblique direction upon the sides; for large works, turn beams or horse gins, which raise the barrows filled with earth, by means of two ropes which wind around the barrel of the gin in contrary directions.

The following method was pursued in excavating the *London docks;* two posts are placed at a certain distance from each other, according to the depth of the excavation; at the tops of these posts are pulleys through which passes a rope, to the middle of which is attached a horse; now, when the horse is at either post, one extremity of the rope is at the bottom of the excavation and the other at the top; to the extremity in the excavation attach a barrow filled with earth, and an empty one at the other extremity, both being upon inclined planes; then by directing the horse towards the other post, the filled barrow commences to rise and the empty one to descend; one man directs each barrow.

Many other machines have been invented for the same purpose, as *Dodd's machine*, worked by men, *Carne's*, by horse power, and *Haskew's Patent Excavator;* for all of which see *The Monthly Magazine*, vol. ii. p. 594.—Tr.

this respect is particularly applicable to canals in mountainous countries, and for working mines to advantage.

Canals of this class are narrow and navigated by boats constructed particularly for them; some of the canals of this class, executed in England, are not more than 10 yards in breadth. By the employment of this system of canals, where large falls are passed by various means, particularly applicable to this kind of canals, a canal may be carried through a region where a common canal could not be employed. This system, of course, occasions great falls, to which the common locks are not applicable; art has supplied this deficiency by the application of more or less ingenious contrivances. These means are, *the balance lock*, *floating lock*, and *inclined plane.*

The controversy which had long existed in France on this system of navigation, ceased on the publication of an excellent work by *M. Dutems, Inspector General of Ponts et Chaussées*, which has put us in possession of all the necessary information respecting this species of works in England, where the extensive employment of it shows its decided utility.

M. Dutems gives a complete account of both species of canals in England.

The first observation we shall make on this double system is, that although they may have different breadths, the locks of the large canals should be of such dimensions as to pass a boat without a great augmentation of expense in water from the small canals.

Boats for large canals are generally from 24 to 25 yards (22^m to 23^m) long, and from 14 to 15 feet broad ($4^m.40$) carrying from 40 to 60 tons (of 2000 pounds). The boats used upon a small canal are from 24 to 25 yards in length and half the breadth of those for the large canals, carrying 22 tons of 2000 pounds each.*

From this disposition it appears that a large lock may receive the boats from the small canal in pairs, and thus the boats from the small canal may navigate the large one without any inconvenience. The most important im-

* The boats used on the Grand Trunk and Birmingham Canals, are seven and a half feet wide, and seventy feet long, and carry a freight of thirty tons (English).—*Strickland's Reports.*

provement required for the perfection of internal navigation is, to construct the locks of such dimensions as to be capable of passing any of the boats in common use; this has been accomplished in England by a correlation between the dimensions of the locks and boats of the different systems.

By means of this relation which exists between all the canals of a system, advantage may be taken of the saving in the expense of construction and in water resulting from the admission of the small system, since it may enter as an integral part into a general system; there should be no hesitation in adopting the small one, when local circumstances prevent the adoption of the large system, and the trade requires the extension of a navigable line of canal, which may frequently be the case; when the small system is adopted, the dimensions should be the English, viz. in breadth from 8 to 9 yards on the surface of the water, and 4 to 5 yards at the bottom, with about 4 feet of water. The small system proposed by Fulton, the American engineer, is too small; it was to be navigated by boats carrying only 4 tons. The inconvenience of such a system was soon perceived, and it was rejected in England, about the time Fulton's work appeared, at which time that country was engaged in forming a *small navigation.*

The major part of the locks in France have no uniform dimensions; in fact boats of the same section of a canal differ in length, breadth, and depth, so that in many cases the cargo must be changed or unloaded in order to pass a lock from one canal to another.

It is desirable that the English system should be imitated in this country.

By means of inclined planes, falls of 20 or 30 yards have been overcome, disposed in such a manner that the descent of one boat will help the ascent of another. Various powers may be applied to this purpose. Fulton published a work in which he proposed various systems of inclined planes, with various manners of generating the power to move boats upon them.

This work, which has been translated into French, presents many interesting details not only on inclined planes but also on iron bridges.

In case of moderate falls, for this system, a communication may be formed by means of the *balance lock.*

This method consists in having a well, filled with water, at the head of the inferior level, sunk as much below the bottom of this inferior level as the difference between the two levels, *plus* the depth of a *float* (or water tight box filled with air) of the requisite magnitude. This float is to support the lock placed upon pillars of a length equal to the fall; consequently when the float is on the surface of the water in the well, the lock being at upper extremities of the pillars, will be level with the upper reach. When the lock is filled with sufficient water to float the boat, it should be *in equilibrio* with the float, consequently capable of being moved with ease from top to bottom of the fall.

When the surface of the water in the lock is level with that of either reach, and one end of it is attached to the frame or gate of the canal (there being two gates near together at the top and bottom of the fall, the space between which is freed from water, one of the lower reach gates being close to the edge of the pit, and one of the upper gates close to the edge of the fall), by screws or other means, the water is to be let into the space between the two gates and then the gate of the lock may be opened and a boat floated in or out as may be required.

Except what water may be required to regulate the equipoise and change of motion, together with that required to fill the space between the two gates, the expense of water is nothing; and with draw doors to the lock, and a single gate for each level, the quantity is very small. The weight of water displaced by the pillars which support the lock or cradle is not material; and when required it is proposed to produce motion by weights acting on a spiral wheel.

This plan, which possesses merit, is applicable in many cases, and has been tried upon the *Ellesmere* canal in *Danbighshire*, on a fall of 12 feet, with success.

The French engineers *Soulage* and *Bossu* invented, not long since, under the name of *movable lock*, a machine for the same purpose as the above; its movement

is founded upon the same principles and appears to answer the purpose intended very well.

The system invented by William Smith, which was put in operation in 1794 at Oaken-Gates, was not found to answer the purpose intended and was abandoned.

In case of a want of water, inclined planes have been employed with success in Great Britain. There are three upon the Shropshire canal which serve to pass large falls, as from 117 to 205 feet and more. *M. Dutems* has described them in his work on England.

The inclined subterranean plane which the Duke of Bridgewater caused to be constructed in the mines of Walkden Moor, is the grandest work of the kind in England. The singularity of the place where this work is constructed and its great utility, justly entitle it to the celebrity which it enjoys. A description of this work may also be found in *M. Dutems* work.

Steam engines have been employed with complete success by the English, where a great want of water is felt, as is frequently the case on small canals.

They serve to raise the water from an inferior reach to a superior one, thus saving all the expense of water.

CHAPTER XXVII.

Rail-Roads and their Construction.—Cost.—Advantages.

The principal object to be obtained in constructing a rail-road is to form hard, smooth, and durable surfaces for the wheels of the carriages to run upon. These surfaces consist of parallel rails of iron, raised a little above the general level of the ground, with a gravel road between them; consequently, a rail-road combines the advantages of good foot hold for horses, and smooth and hard surfaces for the wheels to roll upon. The wheels or rails are furnished with proper guides to keep the carriage upon the rails; and the circumferences of the wheels are made hard and smooth.

The rails for this kind of road were first made of wood,

and were first used in 1680 for facilitating the transportation of coals from the pits.

By using iron, we obtain a smooth, hard, and even surface, at an expense comparatively small; and the moving power has very little more than the friction of the axis to contend against.

In discussing the merits of rail-roads, we have to compare them with turnpike-roads and with canals. From calculation it appears that one horse will draw 10 times as much upon a railway as upon a good road, and upon a canal a horse will draw 30 times as much, when the horse moves at the rate of 2½ miles in an hour, consequently, a canal is the most advantageous mode of conveyance; but when the speed is increased this ratio is reversed.

Speed and certainty are of such primary importance in commerce, that a small increase of expense is not a material object.

Both the first cost and the annual repairs of a canal exceed those of a railway; the excess varying according to the nature of the country. But in a country suited for a canal, the difference of first expense is more than compensated by a greater effect being produced by a given power on a canal than on a railway, provided the motion does not differ much from three miles per hour; and this renders a canal decidedly superior to a railway for a level country. On account of the resistance increasing in the ratio of the squares of the velocities, when bodies move in fluids, and also on account of the injury which the banks would suffer by a rapid movement of the water the velocity of canal boats must be considered as limited to the above speed. But on a rail-road a greater velocity may be obtained with less exertion.

The great advantage of a railway will consist in its affording the means of transporting heavy goods with speed and certainty; if it be only so far as to double the speed of the fly-boats, it must be a material benefit. Up to the present time, no rail-road of any extent or importance has been constructed in this country. They are confined to England and Scotland principally.

Railways are of two kinds, according to the disposition of the flanch or rim, that is to guide the wheels of the car-

riages and prevent them from running off the rail. In the one, the flanch is at right angles, and of one piece with the flat surface of the rail; in the other, the flat surface of the rail is raised above the level of the ground, and the flanch is fixed on the wheel of the carriage at right angles to the tire or iron placed on the circumference of the wheel.

Besides these, another kind of railway has lately been introduced by Mr. Palmer, which consists of a single rail, supported at some height from the surface of the ground; on this two wheels confined in sufficient frame work are placed, suspending the load equally balanced on either side. This arrangement certainly seems to insure the grand principle of lessening friction, and doubtless will, in many situations, be found a great improvement.

Edge Rail-Roads.

In this system (*see Plate* V, *Fig.* 38), the wagons run upon the rounded edge of the rail, which is smooth, and of cast iron, laid as even and regular as possible. The length of the rail is generally 3 feet, with a depth of about 4½ inches in the middle and about 2 inches broad at the top; in some railways, the rails are 4 feet long. The ends of the rails meet in a piece of cast iron, called a *chair*, and the chairs are fixed to blocks of stone called *sleepers*, with a broad base, and weighing from 1½ to 2 cwt. These should be firmly bedded in the ground and adjusted to a proper plane for the road, before the chairs are connected to them.

Wrought iron rails may be used with advantage; they reduce the number of joints, and the difficulty of making even joints has contributed much to their introduction.

A moderate degree of success depends upon the laying of the rails.

The edge railway is best adapted for permanent works, because it is easiest kept in order.

Tram Roads or Flat Rail-Roads.

The rails of tram roads (*Plate* V, Fig. 40), are always formed of cast iron; planks were used, and still are on some occasions. The tram-rail is very convenient for

temporary uses; it is much used in quarries, mines, forming new roads, and digging canals. Tram-rails are very weak however.

As tram-rails are applied with much benefit in forming temporary ways, the most ready way of putting them down is of some importance. The common method is, to fix them with nails or spikes upon cross sleepers of wood. This is inconvenient on account of the difficulty of drawing the nails when it is necessary to move them.

Le Caan's tram-plates are the best, as they are fixed without nails. The plates are joined by a dovetailed notch and tenon; and an oblique plug is cast on each plate, which is let into the stone sleeper. But for the advantage of repairs, at every 30 yards there is a plate with a perpendicular plug. These plugs are 1¾ inches in diameter, 2½ inches long, and have an obliquity of about 8°. A small groove is left in the plug to permit the water to expand. The plate should rest firmly upon the sleepers.

The plates are about 3 feet long, 3½ inches broad on the top, and ¾ of an inch thick, and weigh about 42 pounds. They are variable, however, and should be adapted to the work to be done upon them.

Single Rail-Road, or Palmer's Railway.

On this novel and ingenious rail-road, the carriage is drawn upon a single rail, the surface of which is raised about 3 feet above the level of the ground, and supported by pillars placed at equal distances, about 9 feet apart.

The carriage consists of two receptacles or boxes suspended one on each side of the rail by an iron frame, having two wheels of about 30 inches in diameter. The rims of the wheels are concave and fit to the convex surface of the rail; and the centre of gravity of the carriage, whether loaded or empty, is so far below the upper edge of the rail, that the receptacles hang in equilibrium, and will bear a considerable inequality of load without inconvenience, owing to the change of fulcrum from the breadth of the rail, which is 4 inches. The rail is made capable of adjustment and may be kept straight and even.

The advantages of this arrangement consist in its being more free from lateral friction than even the edge railway.

Moving Powers for Railways.

In the economy of rail-roads it is of the greatest importance to consider the nature and effect of the different species of power that are likely to be applied to them. These are, *horse power*, and *steam*.

When the power of a horse is to be applied to move a carriage on a railway, it is obvious that we should endeavor to apply it in such a manner as will produce the greatest quantity of useful effect, with as much speed as can be obtained without injury to the animal. Hence the two objects of inquiry are, the duration of a day's work, and the *maximum* of useful effect.

The time assigned for the day's work of a horse is usually 8 hours; but we are certain that some advantage is gained by reducing it to 6 hours.

The speed which corresponds to the maximum of useful effect is of considerable importance, as the expense of horse power very much depends on it.

The greatest distance a horse can travel day after day without injury is the limit of velocity, and the work must be nothing.

It is obvious, that when a horse travels at such a rate that the empty carriage is equal to his power, the work done is nothing. On the other hand the load may be so great that the horse can barely move, in which case, also, the useful effect is nothing; but between these two extremes there is a *maximum* of effect, and therefore advantageous.

The velocity which gives the greatest effect is half the extreme velocity when unloaded. The extreme velocity of a horse is 6 miles per hour when continued for 6 hours, and, therefore, 3 miles per hour must be the velocity corresponding to the *maximum* of useful effect, when the time of labor is 6 hours.

Steam power we shall consider when we treat of locomotive carriages.

With respect to carriages for rail-roads, small carriages

are evidently both heavier and more expensive, in proportion, than large ones. The carriage cannot be much enlarged, however, without increasing the number of wheels.

When a carriage has more than four wheels the body must be so sustained that its pressure may be divided equally among the wheels.

The load on each wheel must be limited to suit the strength of the rails; it will seldom exceed two tons on a wheel.

Perhaps the most advantageous load will be about 1½ tons on each wheel, which will require an axis of 3 inches in diameter. The size of the wheels is the next point to be considered; it is well known that large wheels are the best. But, practically, they are limited to about 4 feet 6 inches, or, at most 5 feet if made of cast iron, and if of wood this size cannot be much exceeded without rendering them very heavy.*

When horses are employed to draw carriages on a railway, the traces should be attached so that the horse may draw in an ascending direction, as this direction gives a horse much advantage to draw a load forward. Where considerable speed is to be produced by horses on a railway, it will be necessary either to have the horses behind or at the sides of the carriage in order to prevent accidents.

There are few subjects in the practice of Civil Engineering which demands so much particular information, profound skill, and such extensive views of the effects of trade and commerce, as the selection of a line for a railroad or a canal.

The interests of agriculture must be understood, and such arrangements made as are likely to benefit the land owners through whose land the line passes.

In consulting the interests of a manufacturing district, it must be recollected, that "time is an important element in all commercial transactions."

Where a considerable tract of country is to be examined

* Mr. Strickland says, that the wagons most in use on English Railways weigh three tons, including the lading, running upon cast iron wheels three feet in diameter.—Tr.

the best index to its elevations, is its streams and rivers; these indicate every change of inclination.

In a survey for a line of railway our attention should be directed to the attainment of the same objects as for a canal, except water only; the plan for a rail-road is made in the same manner as before laid down for canals.

But, in proceeding to fix the exact line, it ought to be ascertained, whether the trade will be an equal one in both directions or not. If an equal trade is likely to be established, then the line should be as level as possible. If a permanent unequal trade be the only one that can be conducted by the railway, and many will be of this kind, then, there is one inclination best adapted for the trade. The following is the practical rule for finding this inclination.

*Rule.** To the tonnage in each direction add the weight of the wagons required to carry the greater tonnage, divide the greater sum by the less, and make the quotient, diminished by one, the numerator, and the same quotient with 1 added, the denominator of a fraction. Multiply this fraction by the fraction representing the resistance on the level rails, and the result will be the fraction showing the best inclination for the trade.

Suppose that for every 1000 tons of goods or minerals that will go in one direction 500 tons will be returned; and let the weight of the wagons to carry 1000 tons be 250 tons. Then 1000 tons added to the weight of the wagons will be 1250 tons. Also, to 500 tons add the weight of the wagons, the sum is 750 tons. Divide 1250 by 750, it gives 1.666. Then subtract 1 for the numerator and add 1 for the denominator, and we have $\frac{.666}{2.666}$ $=\frac{1}{4}$. Now, if 1*lb.* will draw 130 *lbs.* on a railway, $\frac{1}{4}\times\frac{1}{130}=\frac{1}{520}$, or the descent should be one part in 520, or near 10 feet in a mile.

The inclination being determined, we proceed to ascents and descents.

Where either horse power or the steam carriage is to be employed, every ascent or descent, which cannot be

* For the demonstration of this rule, see note at the end.—Tr.

overcome without the aid of a stationary steam engine, must be avoided, unless the expense of cutting and embanking will exceed the delay and expense of an engine, &c.

When stationary engines are to be employed throughout the line, the height of the ascent or depth of descent is immaterial, provided it be not too abrupt and deep; and the deep cutting may be avoided. Embankments should be made firm, and the slopes of embankment and excavation should be such as to prevent their injury from the weather.

Where good stone is at hand, a ravine may be crossed by arches similar to ancient aqueducts.

It is desirable that all rail-roads should be of the same breadth; generally this breadth may be limited to 4 feet 6 inches for heavy goods, and 6 feet for light carriages. For a single track the breadth to the outside of the rails 5 feet, 3 feet on each side for paths, and 4 feet on each side for hedge and ditch, or a total width of 19 feet; if the track be 6 feet wide, 21 feet will be required. For a double track, 28 feet for heavy carriages and 32 for light ones. A double track for each species would not require less than 56 feet.

On all rail-roads there should be passing places at certain parts of the road; these are composed of one double, and two single branches, their top surface having a groove so that the rim on the wheels may move in it when turned off from the straight line by the single branch or tongue; in single tracks these should be frequent.

We now proceed to the *construction* of rail-roads.

There are two kinds of rails which succeed in practice; these are the cast and wrought iron ones. Wrought iron does not last so long as cast iron when exposed to the air and weather. A cast iron rail is more liable to fracture than a wrought iron one, even when made of the best of iron, and the force that would break a cast bar would only bend the wrought iron one, which would not interrupt the traffic on the road.

The form of cast iron rails should be such as to give the most strength with the least material. The breadth being uniform, the outline of the depth should be a semi-ellipse, so that the rail may be equally strong at every

point. To settle the cross section of a rail, the breadth of the upper edge should be fixed, this breadth should be proportioned to the load to be supported and the size of the wheels; the larger the diameter of the wheel, the greater the surface of contact; and, consequently for large wheels less breadth is necessary. The breadth of the top should be an inch for each half ton of stress on one wheel.

The mean thickness should not be less than half the breadth of the upper surface; and the least thickness not less than ½ an inch.

Malleable iron rails have been applied only as edge-rails. As wrought iron is as soft, if not softer, than cast iron, it is obvious that the rails should be at least equal in breadth on the upper surface; the following are nearly the dimensions for these rails: An inch in breadth at the top for each half ton of stress on one wheel, and the average thickness, ⅜ of the top breadth.

Wrought iron rails are far preferable for roads where it is proposed that the carriages should travel faster than 3 miles per hour, on account of the great danger arising from a broken rail. Roads formed for the reception of rails should have all the accessories belonging to a common road for carrying off the water, &c. A continued trench should be formed under the rails, about 2 feet broad and 10 inches deep, and filled with small fragments of stone upon which the sleepers or blocks are to be placed. These blocks should be about 16 inches square, and in thickness about half the base. In a soft soil the trenches should be deeper and broader, and well filled with stone.

In districts subject to severe cold, the sleepers should be much larger and greater precautions used in laying them.

Rule for the best Length for Rails of Rail-Roads.

The price of a ton of iron delivered on the rail-road must be known, and also the price of the chair, stones, and setting of one support. Then divide the price of a ton of iron by the price of one support, both being in dollars; square the quotient and multiply it into the breadth of the rail in inches, and this product by $\frac{1}{10}$ part

of the weight of the loaded wagon in pounds, and extract the cube root of the product. Divide 700 by the cube root found and the result will be the distance in feet.

This is for cast iron. Every precaution should be adopted for keeping the rails dry.

Locomotive Engines.

A locomotive engine is a steam engine placed on wheels, in such a manner, that the force of the engine can be applied to impel these wheels and by that means draw along a train of wagons.

It may be thought by some that rack work is necessary in order to cause the engine to move on the rail surface, but it has been found that with a proper inclination to the rail and pressure on the wheels, there is no danger of the wheels sliding.

In consequence of the small weight and simplicity of the operation of high pressure steam engines, they alone appear to have been used on rail-roads; they work at a pressure of from 30 to 50 pounds on the square inch, above the atmospheric pressure.

If human prudence could be relied on, all the objections to this kind of engine might be obviated.

The velocity of this kind of engine, is limited only by the expense and risk of accident. But there is a velocity for steam engines which gives the *maximum* of useful effect, as well as in horse power.*

The *maximum* power depends on the structure of the engine. If the steam piston exceeded a certain velocity it is obvious that the boiler would not be capable of affording the requisite quantity of steam; the moving force and length of the stroke, when the resistance is the friction of the piston only, limit the velocity of the piston.

Twice the proper velocity of the steam engine produces the *maximum* of useful effect, as in the case of horse power. Low pressure engines are deemed unfavorable for moving steam carriages, on account of the complexity of the apparatus, and the weight of water necessary for

* Mr. Stickland says that, in order that a locomotive engine may be used with advantage, the road should not deviate more than $\frac{3}{16}$ of an inch to a yard from a horizontal.—Tr. or 1 in 192 = 27 feet per mile.

condensation; and the bulk occupied by the one and the immense quantity of the other, render it quite improbable, that they can ever be employed with much advantage.

Fixed, or Station Engines.

Conceive that the whole line of road is divided into short stages, and that an engine is placed at each of these to work an endless chain, extending the whole length of one or more stages, and running upon pullies or rollers; also, that by simply moving a handle of a lever to a friction apparatus, a carriage can be connected in an instant, if necessary. Thus any quantity of carriages could be moved at the same time, not exceeding the power of the engine.

We next proceed to compute the extent to which motion could be conveyed by an endless chain supported on rollers.* The greatest stress a chain ought to be exposed to, is equal to the weight of half a mile of chain; consequently, the weight of chain to serve for one mile will be twice the moving power of the engine, supposing the engine to draw in both directions at the chain; but if the rollers be properly formed the friction will be only about $\frac{1}{100}$ part of the weight of the chain, and consequently $\frac{1}{20}$ of the power will be lost in moving it, when the engines are $2\frac{1}{2}$ miles apart, and so on, till at 50 miles apart, the whole power would be expended in moving the chain.

From 8 to 10 miles may be considered the greatest distance from station to station to be adopted in practice.

It is obvious that a system which requires an engine at every tenth mile is only adapted to an extensive traffic.

The *maximum* velocity for a low pressure engine bears the same relation to the length of the stroke as in a high pressure one.

We now come to consider the most important point in all systems, the expense.

The first cost of a rail-road must be considered, then the annual expense and the rates of tonnage that will be equivalent to it, supposing the probable tonnage to be

* Ropes are frequently used for the same purpose; they are generally about one mile in length.—Tr.

ascertained. In calculating this expense, the following are the principal items to be considered.

1. Expense of examination, surveys, superintending the works.

2. Value of the land required, expense of ditches and drains, &c.

3. Expense of cutting, embankment, and levelling.

4. Expense of bridges, tunnels, aqueducts, &c.

5. Expense of road, and (stone) sleepers.

6. Expense of rails, chairs, pins, and fixing the same.

7. Expense of engines for inclined planes, chains, rollers, &c.

8. Amount of damage to property, and small expenses.

The average cost of a proper railway with a double set of tracks will not be less than 23,000 dollars per mile, when all the expenses are paid. It is stated that in England the average of a number of railways, of all kinds, containing 500 miles, is nearly £4000 per mile, and allowing for imperfections, they will now cost £5000 per mile. The same author estimates the cost of a canal, under similar circumstances, at double that of a railway, £10,000 per mile.

The first cost of a turnpike with 16 feet of well-made road will, on an average, cost $5000 per mile.

It has been found in England that it will cost 2.4 farthings sterling to transport a ton one mile on a rail-road, when the carriage is moved by horse power; when the locomotive engine is used, it will cost .43 of a farthing per ton per mile; if by means of stationary steam engines, it will cost 1.68 farthings.

When it is recollected that on a railway goods may be propelled with more than twice the velocity that can be had on a canal, without an increase of expense for the conveyance, we should think it rarely advisable to cut a canal in preference to making a railway, except in certain cases.*

For further details upon railways the student is referred to "Tredgold on Rail-Roads," and "Wood on Rail-Roads," from which works the above details are extracted.

* For a short description of *Marine Railways*, see note third, at the end.—Tr.

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CHAPTER XXVIII.

Definitions.—Tides.—Effects of Waves.—Works constituting a Harbor.

In France *sea works* are designated to be such works as relate to sea navigation; they are divided into two classes, *harbors* and *roadsteads*.

Under the name of *harbor* is generally comprehended not only the harbor proper, but also all the interior establishments relating to navigation, civil as well as warlike.

Properly speaking, a harbor is a space situated some distance inland, where shipping may lie free from agitation either from wind or tide.

Harbors are of two kinds, those which are constantly full, and those which are influenced by the daily phenomena of the tides, which are principally felt on the ocean, and but feebly on inland seas. These considerations naturally cause a difference in the works composing harbors.

The flux and reflux of the sea cause the tides, the former being the flood tide and the latter the ebb tide.

The duration of each tide is a little more than 6 hours, that is, during a little more than 6 hours the tide rises, remains stationary for a moment and then falls, and continues to decrease for a little more than 6 hours; then begins to rise again.

In consequence of this alternate movement, the same tides return every 15 days, with the difference that morning tides become evening tides.

The greatest intensity of these phenomena takes place near high and low water; and their most marked effect is generally two days after the syzygies and quadratures; the syzygies are the full and new moons, and the quadratures are the quarters.

The highest tides of all, are at the equinoxes; and the lowest at the solstices.

These phenomena, in duration and intensity, are more or less influenced by winds.

It is not our object to explain the causes and laws which influence the tides; in M. Laplace's excellent work, *Mécanique Céleste*, these are explained; we shall consider them only as they may influence marine constructions.

The theory and effects resulting from this movement of the tides as far as it is necessary for the proper disposition of the works forming a harbor, are easily explained by observation.

Opposite to every bay or inlet a secondary current is detached from the main current, which being solicited by two forces follows the diagonal of the parallelogram, the sides of which represent these two forces, and strikes the shore some distance beyond the bay which it should enter. This secondary current is afterwards decomposed, a part of it forms a counter current and returns to the bay, another follows the direction of the principal current until another bay to be filled occasions a new counter current.

These counter currents have many different names. In the English Channel they are called the *verhaules.* They are indicated by lines of froth on the surface of the water; vessels frequently profit by these indications of a current.

On inland seas these currents, resulting from tides, are scarcely felt. In the Mediterranean they are called *shore-currents.*

The combined action of the winds and tides cause waves.

Observation has shown that the motion of waves is only an oscillatory motion; it is only at the surface that a motion of translation takes place. Waves destroy such parts of a coast as are not composed of solid rock, and transport and deposit the *débris* upon other parts, but principally in such parts as correspond to valleys, into which the prevailing winds force them.

The direction and quantity of these deposits may be exactly enough known by observation; this knowledge is indispensable for correctly placing the works for harbors, and in general for all sea works.

Calculations and considerations on the direction of these deposits constitute the object of a *Mémoire* drawn up by *M. Lamblardie, Inspector General of Ponts et Chaussées,* an engineer of the first merit; from experiments and observations made upon the Normandy coasts, and first printed in 1789; into which is collected all that a strict observation of the phenomena of the tides, winds, and

other causes could present, as applicable to the construction of marine works.

From the consideration of the tides and the alternate currents produced by them, the alluvial deposits produced by the winds, and the almost continual agitation of the sea, there results a necessity for constructing certain protecting works, which shall furnish vessels with a sure and safe shelter from winds and waves, the whole of which works constitute a harbor or port.*

To enable vessels to enter harbors easily, and to prevent alluvial deposits from obstructing the entrance into them, jetties have been devised.

Inside of these exterior works, the port is made; but if the question is with respect to a seaport which the tide leaves, the water running out, and if this port is to receive large vessels which cannot support their own weight on the bottom without injury, basins or docks

* In making surveys for artificial harbors or for the improvement of natural ones, the depth of water is an essential element of the examination. The following is the method employed by engineers of merit for obtaining this element.

If the depths of a large number of points of the bottom below any fixed surface are obtained, and through those points which are at the same distance below this surface, we draw lines, we shall have a complete representation of the bottom sounded, similar to the representation of a hill or mountain according to Senator Monge's method, alluded to in the body of our "Course."

To obtain points of the bottom, a boat is rowed steadily from one point of land to another during which a lead is thrown at regular intervals of time marked by a time glass; the depth of each throw is recorded. Now if the line passed over, is drawn upon the map of the survey, and divided into as many equal parts plus one, as there were throws of the lead made in passing over it, the points of division will show the points sounded, and the depth of each point may be marked. In the same manner any number of lines may be sounded.

The minuteness of the sounding, evidently depends upon the intervals of time between the throws of the lead, which again depends upon the depth of water, the deeper the water the longer time required to draw up the lead. The soundings may be made at any time of tide by having a fixed stake, and knowing the depth at this stake at low tide. The surface at the lowest tide should be the one to which the depths should always be referred.

Cases may occur where we have but one point of land, or one of the points is too far distant, as in a large bay with a straight shore, when the following would be the method for obtaining the soundings.

Definite lines should be run on the shore from low water line, and as nearly perpendicular to it as possible, which should be marked by stakes; where these lines cut the line of low water, a strong stake should be placed, as long or longer than the rise of the tide. At the time of sounding, a theodolite or spirit level with a compass, should be stationed at some fixed point, from whence as many of the above lines can be seen as possible; every thing being ready, the boat commences at any one of the stakes at the low water line, and is rowed in the direction of the line marked, of which the place of starting is one point, and the lead thrown as before; when the boat has reached such a depth as is required, a signal is to be made to the person stationed at the instrument who takes the bearing; the intersection of the line of bearing with the line passed over by the boat gives the extremity of the line sounded; the soundings may be plotted, as above, using the same precaution to refer them to low water.—Tr.

have been formed which are kept always full of water. It is around these basins or near them that the magazines and other marine establishments are placed. A channel limited by two jetties communicating with the sea, a harbor which is not always full of water sufficient to float vessels, together with basins and docks, form the principal works of an artificial harbor on the sea board.

There are other works which serve to complete the works of a harbor, as the outer-harbors, the wet-docks dry-docks, sluice-gates, clear-ways and ways for repairing vessels.

We shall now proceed to examine each of these works and their disposition, as well as the accessory parts.

CHAPTER XXIX.

Jetties.—Outer-Harbors.—Clear-Ways.—Sluices.

Jetties.

A jettie is a species of dyke, the direction of which is perpendicular or a little inclined to the shore, and advances more or less into the sea. On the Mediterranean these works are sometimes called *moles*, but their use is the same as the jettie. Besides, a mole, properly speaking, is a work advanced into the sea and generally isolated, and intended to cover the entrance into a harbor; such as the *Civita Vecchia*. Properly speaking, jetties bound the channel; which is a canelled space connecting the sea with an artificial harbor.

The position of jetties must correspond with the principles laid down with respect to the direction of the deposits from the adjacent shores, and at the same time facilitate the entrance of vessels into the harbor, and also preserve smooth water in the same. Where a channel is confined between two jetties, it is evident that the one on the prevailing windward side, should be the longest; by this disposition, deposits of sand or other substances will be prevented from entering the channel, but are deposited against the exterior face and the head of the jettie.

In this respect it forms a kind of support; at the same time it must be acknowledged that these works do not fulfil completely the purpose intended; the abundance in which these deposits take place under some circumstances extend and prolong the bars and banks, and sometimes they rise above the coping of the work, and then they enter the channel and communicate against the interior faces of the jettie, and soon form a bank or bar, which it requires accessory works to expel; to all of which many of the French ports are subjected.

V It has been found that winds which prevail during some time in such a direction as to make an angle of 45° with the shore, very much favor the deposit of sand and other alluvion. Observation agrees with theory in this respect, that alluvial deposits take place in the greatest abundance when the wind is in the above direction with respect to the shore.

The system of jetties has been frequently abused by their excessive length. After the abuse in length of jetties, which gives to this work but a limited use for arresting the accumulation of alluvion, piers were applied to the same purpose; they were connected to the shore, and placed on the prevailing windward side of the entrance into the harbor; these works projected into the sea under the form of jetties making different angles with the shore, and in positions pointed out by little or no reflection; but these piers are only intended as palliatives against the deposit of sand, &c. and as they fulfil in a very imperfect manner the purpose intended, they should never be used when the object is to stop these deposits only.

The necessity of obviating the insufficiency of jetties against the deposits of alluvial substances, led to the application of sluices; this is the most expeditious and economical method of removing this obstacle from an obstructed channel.

In order to facilitate the movement of vessels in and out of the harbor the windward jettie should be the longest. In fact, it is absolutely necessary, for when a vessel leaves the port with a head wind she must be towed to the head of the windward jettie, and if both jetties were of the same length, or if the leeward one were the longest,

the vessel would strike this jettie on the first tack, as the wind tends to drive her against it.

When local circumstances prevent this disposition, buoys should be fixed out beyond the jettie for warping the vessel out beyond the leeward one.

The jettie is generally curved, the convexity turned towards the prevailing windward side. The channel between the two jetties should be broad enough for three of the largest class of vessels which can enter the harbor, to pass abreast under sail. When a sluice is necessary it should be so disposed, that there shall result a force of water necessary to produce the desired effect upon the alluvial deposits, an effect which will evidently depend upon the height of water resulting from the breadth of the jettie channel, together with the velocity of the water from the sluice.

The extremity of the jettie which is towards the sea should have the semicircular form and sufficiently large, independent of the resistance which it should afford against the winds and waves, to contain a lighthouse or beacon to direct vessels into the channel. A few pieces of cannon may also be placed there for giving signals.

The curved form for a jettie evidently covers the harbor and protects it from winds; whatever may be their direction they cannot enfilade the channel; this form also contributes to increase the effect of sluices; the current, according to the laws of circular movement, tends to escape in the direction of a tangent to the curve, which necessarily carries it against the concave side of the channel, where the greater part of the obstructions accumulate, as well as around the head of the jettie; consequently, the current produced by the sluice striking the concave side, is reflected against the head, provided the sluice gate is properly placed.

The thickness of a jettie is generally regulated by the breadth which it should have at the top for facilitating the towing and unloading of vessels. In conformity with this, they are generally made about 12 feet thick; experience has shown that this is sufficient to resist the waves.

Jetties should be so elevated that the highest tides will not overflow them; upon the interior they should be 4 or

5 feet above the highest water. But the safety of the lighthouse and the guards placed there to assist ship-wrecked and distressed vessels, requires that this part should be elevated above the rest of the work; and in order to prevent, as much as possible, the sea's rising above it, the slope of the wall should be suppressed near the top and raised vertically, in order to break the force of the waves and throw them back.

It has been found that even this disposition for a jettie does not always procure smooth water in the harbor, although protected from the winds. When the sea is much agitated, the waves enter the channel and are held up by its narrowness, which prevents their spreading, and thus enter the harbor. In order to counteract this effect, works called *clear-ways* are used; they are placed in the sides of the jetties and sometimes in the sides of the outer harbor.

Clear-ways are cuts made in the jetties near the interior extremity, and are long inclined planes, placed within the cuts; and, in order to keep up the communication along the jetties, a bridge should be placed across the opening, from thence they have been called *clear-ways*.

The object evidently of these works, is to permit the waves, which are kept at their full height in the channel, to spread. This expansion which the clear-ways enable the waves to take, evidently reduces the height of the waves, and the inclined planes smooth them down gradually. These works are a modern invention; and as they are not expensive, they should always be used where circumstances will permit.

Outer Harbors.

The outer harbor is that part of an artificial port which is immediately within the jettie and without the docks; it is generally dry or nearly so at low tide.

This part of the port is intended to shelter such vessels as can support their own weight, as they will ground when the tide retires; it also furnishes a shelter to small craft, such as fishing and coasting vessels, which, owing

to their slight draught of water, have no occasion for a full tide to enter or leave the harbor. The outer harbor is also useful for vessels coming from sea, they may there shorten sail to prepare for entering the docks, which they cannot do under sail. For this purpose the outer harbor should be large enough to enable vessels to manœuvre, which requires two cables length at least, square dimension. If local circumstances prevent this disposition, it must be supplied by an extension on one side. The outer harbor of *Havre*, is an example of this method of supplying the deficiency of nature. Several of the channel harbors have this essential condition also, owing, however, to a happy combination of circumstances rather than any premeditated design. *Dieppe* and *Fécamp* have such dimensions as enables vessels to shorten sail with ease, which is a very great advantage.

Around the outer harbor are constructed the docks for discharging and constructing vessels, also the ways for paying the bottoms of small vessels, such as can support their own weight, as well as the dry docks for repairing large vessels.

The wharves, which should be constructed round the harbor and outer harbor, should be large and commodious. This condition is necessary for loading and unloading vessels. The breadth of these wharves should depend upon the activity of commerce of which the port is susceptible. In general, they may be from 50 to 60 feet broad. Buildings for the convenience of traffic should be erected around these wharves, they serve to shelter the vessels.

Sluices.

These are accessory works constructed for carrying off the alluvial deposits. This effect is produced by means of a large mass of water being collected into a reservoir, and at low water precipitating it with a velocity due to the height of water in the reservoir, upon the alluvial deposits. The water is let out by means of one or several outlets, which are shut by means of gates of various kinds, which are opened in the most expeditious manner possible. The most simple system of gates, is the simple

sliding gate between two posts, raised by means of a windlass, rack, or screws. This method has the inconvenience of requiring a great force to work it, as the gates should be of considerable magnitude in order to produce the desired effect. With this system it would require complicated machinery to produce the required force with a few men, besides, the movement would be extremely slow, and the effect of the sluice is proportionate to the quantity of water thrown out at the same time. The gate should not be entirely opened, until a part of the water flows out, which produces the greatest effect; the object of sluices fails unless, in order to avoid the large gates, several smaller ones are constructed, which again is objectionable on account of the expense.

The system of sliding or turning gates for sluices prevents the use of the reservoir for navigation, as the supports for the gates prevent vessels entering them.

The inconvenience should be remedied by adopting a system of gates which will answer both purposes; this is particularly the case in Holland where the basins serve as reservoirs, and where many kinds of gates have been tried.

The Dutch use large mitre-sill gates in which small turning gates are placed, which shut and open of themselves; independent of these large gates, culverts are placed in the cheeks of the gates, by which a rush of water is produced, as at *Flessingue*. In all these methods, however, of saving water, there is some danger of either emptying the basin so that vessels will ground or the quantity of water let out will be so small as to produce no effect upon the alluvion. In France, where powerful sluices are required to carry off the deposits, reservoirs are constructed independent of the basins and docks; they are placed as near the channel as possible. The system of *coupled-gates* is generally employed at this time; although these gates answer the purpose intended very well, yet they are not exempt from defects; since their invention, for which we are indebted to *M. Castin, Director of Fortifications*, some alterations have been made, and still they are susceptible of further improvement.

These coupled gates are very simple; the opening for

the gate is divided into two unequal parts by a post, on which, or about which, the gates turn. From this disposition it is evident that the pressure depending on the height of water, determines the direction in which the gate will swing. To prevent the gates swinging in any direction (to which the pressure tends,) catch posts which confine the gates when shut, are placed on each side of the opening; by turning this post we are able to give a large quantity of water at the same moment. The movement of all turning gates, whether isolated, or coupled, is founded upon the inequality of surfaces, against which the water presses.

Small turning gates in large silled-gates, are not solid, their adjustment in the large gates alters the arrangement of timber of which it is composed. This consideration has led to new researches for a substitute which has not this objection. In Holland a kind of gates has been employed which answers for both navigation and a sluice.

This is composed of two mitre-sill gates turning in contrary directions, the points of the sills being towards each other. It is indispensably necessary for the play of this system, that the flood gates, or those upon the inside of the basin, should be a little wider than those on the exterior or ebb gates, so that the former will lap a little over the latter, (the points of the mitres touch or meet) so that when the flood gates are opened they must necessarily draw the ebb gates with them and place them in their recesses in the walls.

These gates are worked at low water by drawing the water from the triangular spaces between the gates, either by means of gates or culverts.) In proportion as the water in these spaces lowers, the equilibrium in the same ratio, is destroyed and the flood gates forced open, drawing with them the ebb gates, thus produce the effect of a sluice.

The advantages of this kind of sluice are incontestable, and they should always be employed in such works.

The stream produced by a sluice should never cross, more than possible, the outer harbor, as it is very injurious to vessels, which may be grounded in the harbor.

This consideration should induce us to place our reservoirs as near the channel as possible.

From experiments made upon the time of efflux and effect produced by several sluices, we have some of the elements necessary for establishing a reservoir. It has been found that 443,000 cubic metres (about 116,952,000 gallons) of water will run through an opening of 12 square metres (about 40 square feet) in an hour, with an initial velocity due to the height of 15 feet; and this quantity of water will fill a channel 27^m in breadth (87 to 90 feet) with sufficient water to remove all alluvion; thus, by adopting for the dimensions of the reservoirs, and the breadth of the sluices, factors which shall give the above products, we shall be sure of producing similar effects or those proportionate to them, agreeably to the above experiments.

The most advantageous form for a reservoir with respect to the greatest facility for bringing the water to the gates, is the semicircle, the sluice occupying the centre of the circle; local circumstances, however, seldom permit this form to be adopted, but in all cases oblong reservoirs are to be avoided.

Reservoirs are generally filled from the sea; rivers and brooks should not be received, because they bring alluvial deposits with them, and they embarrass repairs for the sluices.

The introduction of a river into a reservoir obliges the sluices to be opened every day, unless there are waste-weirs or discharging sluices; and during freshets the sluices must be kept constantly open, which is very injurious to the platform of the bottom of the sluice, and occasions the rapid decay of the works. It is evident from the above observations that rivers should not be admitted into reservoirs, or into the basin. The construction of sluices requires the same precautions with respect to appareil and foundations as other sea works of a similar kind, and should be constructed to resist great shocks; particular attention is requisite in the construction of the platform or bottom of the sluice, and also in the lower courses of the side walls; they should be made of a hard

stone in large masses, with the best of hydraulic mortar, in order to resist the effect of the falling water.

In advance, and in rear of the sluice, a bottom must be constructed; in advance of this, a false platform must be placed in order to remove all liability to undermining, which is liable to take place in this kind of work.

Great attention is necessary to keep such works in repair; their durability depending upon the care observed in their use, which should be discreet.

CHAPTER XXX.

Basins.—Dry Docks.—Stone and Wood Wharves.—Sea Walls.—Roadsteads and Breakwaters.—Conclusion.

Basins, or Wet Docks.

The use of basins or wet docks, is to keep vessels constantly afloat, which cannot be done without a deep harbor or a confined space of water. Around wet docks are arranged all the works and buildings necessary to facilitate commercial operations; such as warehouses of different kinds, adapted to contain the usual species of imported and exported merchandize; the necessary kinds of mechanics should be placed near the wet docks, of every commercial place.

Construction of Wet Docks.

Wet docks are either formed by an excavation of the earth, near a natural or artificial harbor; or by enclosing a part of the harbor itself. In the former case, the dock is connected with the harbor by a short canal with proper gates; in the latter, it is separated from the harbor by its wall and gates only.

Suppose the former case, the first thing to be done is to fix its dimensions and form; its dimensions should be regulated by the wants of commerce; and this depends upon the number of vessels and their dimensions, which it is

contemplated the dock shall hold at one time. The form, should be the most convenient for the arrangement of the vessels, that is, rectangular. After the proper surveys, plans, and estimates have been made, the canal part should be made, as this will facilitate the transportation of materials, &c. The canal must be walled, an inverted arch will be found best for this kind of work, laid upon a proper foundation; the walls should be formed of hard stone. The excavation for the dock walls should next be formed. The walls of the best docks in England are built of stone; the ashlar of hard and the rest of soft stone; the walls should have an inclination of $\frac{1}{7}$. The foundation should be an inclined plane, with an inclination from the front to the back of $\frac{1}{7}$, in order that the wall may be laid perpendicular to this surface. When piles are used, they should be driven with an inclination of $\frac{1}{7}$. The spaces betwixt the piles must be filled with gauged and axed stones laid in full mortar. The stones for the wall should be perfectly dressed and laid in *grout*. The foundation of such works, is generally laid by means of a coffer-dam formed of cast iron sheeting piles.

The communication between the outer harbor and basin or dock is preserved by means of an ebb gate which has the point of its mitre-sill towards the interior; from motives of utility a flood gate is sometimes added.

This disposition permits vessels to enter the basins at high water; when the level of the water of the harbor is above that of the basin the gates open, and when the level descends the gates shut, and the basin remains full.

For the passage of large vessels and frigates an opening of from 13 to 14 metres (14 or 15 yards) is required, and still larger for ships of the line. The plan and disposition of a dock-lock are governed by the same principles as for a canal-lock, differing only in dimensions, which must be limited by the size of the vessels, the height of the water, and many other considerations presented by the locality.

The tides which increase from one quadrature to the syzygy necessarily open the gates every day, and a certain quantity of water enters the dock. During the decreasing tides the gates will not open of their own accord. In

which case, if it is required to introduce or let out a vessel, the level of the water in the basin must be reduced to that of the sea by means of culverts of sliding gates, in which manner the basin performs the part of a lock, and thus vessels may be admitted at any time.

It is advantageous for the safety of vessels to employ a double system of gates; this disposition enables us to guard against accidents, which may happen to the gates, in consequence of which serious injuries might happen to vessels in the dock; they may also be useful in case of repairs. Through motives of mistaken economy, and local obstructions to the easy construction of them, the greater part of the ports on the sea board are not supplied with this double system.

Dry Docks.

Dry docks are works constructed for building or repairing vessels in; they are made near harbors, and are so constructed that by being filled with water, a vessel may be floated into them, and then being closed, and the water exhausted, the vessel to be repaired is then dry, and sets upon an even keel; or the water being exhausted, a vessel may be built therein, and when finished, the dock being opened and filled with water, she may be floated out.

The dimensions of a dry dock evidently depends upon the size of the largest vessels to be built or repaired in it. The best form for a dry dock is nearly the form of a vessel, or rather the form of the bottom section of the vessel made by a horizontal plane through the high water line.

Dry docks should have their longest axes perpendicular to the line of the shore where they are built; the stern part of the dock should be as near the high water line as possible; at this part of the dock is placed the gates and head planks.

Dry docks should be water tight, and therefore, their foundation must be prepared in the most careful manner. The side walls and head, are laid with cut stone and regular retreats, from the bottom to the top, with proper *gang-ways* for the descent to the bottom at certain intervals.

The dock is closed by means of a pair of gates at the

river extremity, which have their point towards the stream; the part without the gates, should have the reversed arched form, with grooves for the stop planks.

The water is exhausted from the dock by various hydraulic works; the steam engine, working chain pumps, is the best arrangement for this purpose. Dry docks should be housed over with proper frame work.

There are no particular difficulties in the construction of the walls of docks and wharves. They are generally of stone; bricks may be used with economy. In case of brick and stone being scarce, and wood abundant, or when expedition requires a tempoary work, a wharf may be made of wood, or the facing of wood and filled in with earth; in the latter case a staccado is made against which the earth rests. This work is composed of several pieces of timber notched to the piers at various heights; shores and braces to oppose the pressure of the earth, and the intervals between the notched tie-pieces are filled by plank or jointed timbers which sustain the earth.

The top is laid with beams, and earth or plank forms the top of the wharf. A cap of large dimensions should go around the whole, forming a kind of curb for the road way.

The whole of this work should be tarred over with care;* but whatever precautions may be taken with this kind of wharf it lasts but a short time, and however cheap it may appear, masonry is far preferable.

The details into which we have entered on the principles which should guide an engineer in forming and executing a plan for a harbor, are particularly applicable to seaports where the tide ebbs and flows, but may answer for those constantly full, differing only in the *means* of construction.

The fall of the tides facilitates much the construction of hydraulic works; foundations in such cases are generally laid by means of coffer-dams, which are overflowed at high water, and the water exhausted when the tide falls. In the Mediterranean, foundations are laid by sinking large stones, or by means of rubble stone mortar

* This is injurious to wharves; tar preserves wood protected from water, but does not conduce to the preservation of that which is wet. Charring that part which is in the ground will preserve it many hundred years.—Tr.

with caissons ; there are almost as many methods as there are localities.*

Our limits will not permit us to proceed further on this subject, the principles laid down for the construction of the various kinds of hydraulic works are more or less applicable to sea works.

Roadsteads and Breakwaters.

Roads or Roadsteads are spaces of the sea, covered and protected from the winds, where vessels may *come to* from a storm, or where they may await a favorable wind in safety.

They may be open and free, or covered and special. The roadsteads of *Brest* and *Toulon* are covered, but the greater part of the roads in France are open and free.

A good roadstead requires a smooth sea, deep water, and good anchorage, with an easy access, and should be defended against an enemy by fortifications.

Breakwaters are such works as are erected for the improvement of roadsteads, and generally consist of a large barrier against the sea, constructed of stone.

Specimens of this kind of work are found in France and England. The breakwaters at Cherbourg and Plymouth are splendid examples of this kind of work.

The success of these works is no longer problematical; they have been found to answer completely the purpose intended.

Conclusion.

From this sketch, doubtless too rapid, of what we have been able to collect on the principles of constructions, the formation of plans, and the best form to be given to the various parts of public and private works, it is easy to perceive what an immense field is open to the engineer charged with projecting and executing the various works, civil and military, of a state.

* In France it has been proved that caissons are more expeditious and cheaper than coffer-dams. The cast iron sheeting piles shown at *Fig.* 43, *Plate* VI, may be used with great advantage in laying the foundation for sea works.—Tr.

In pointing out to the student an object of public utility, the details of which are contained in this "Course," he is reminded of the wisdom of an institution* that so skilfully directs his instruction, to enable him to apply his knowledge to subjects as varied as they are important; and his success will be ample compensation to his instructers for their cares and labors.

* It will be recollected that this *Course* was first orally delivered in the form of *Lectures* to the students of the Royal Polytechnic School of France.—Tr.

NOTES.

Graphical method of resolving without calculation the principal problems relating to the Form and Dimensions of Stone or Brick Walls for supporting Earth or Water.

Extract from M. de Prony's work, entitled "Recherches sur la Poussée des Terres, etc. Paris, 1802."

Use of this Method.

Plate VI, *Fig.* 41. Construct a rectangle $ABCD$, such that AD being divided into 100 parts, AB shall contain 55 of these parts; make AE equal to 30, and AF equal to 45 of these same parts.

Divide AE, which we will call the *line of slopes*, into 60 equal parts; FB, which we will call the *line of specific gravities*, into 30 equal parts; and from each point of division of AE and FB draw right lines to the point D.

The divisions of AE are numbered from 1 to 30 by placing the numbers at every fifth division; and FB from 60 to 90 by placing the numbers at every tenth point.

The figure in this state will serve for tracing the profiles of walls, when the earth which they are to sustain is liable to swell, or have but little cohesion among its own particles; but as we have observed, it is not best to exceed these limits in many cases of common practice, but to sacrifice every consideration to solidity. But if we are certain that no possible change in the state of the earth can vary its natural slopes beyond a certain known limit, the thickness of walls may be reduced by a simple rule, the graphical execution of which is founded upon the following *tracé*.

Make TC equal to FB, and project down upon TC the thirty divisions of FB; describe concentric arcs from the line DC to DA, the common centry of which is D, and the radii equal to the distances from D to the different divisions of TC. Divide CH into degrees (each degree will be the $\frac{1}{60}$ part of the quadrant for the sexagesimal division, or $\frac{1}{100}$ for the centesimal, draw in the angle BDC, through the points of division of the quarter of a circle CH and through the centre D, lines prolonged to the line CB. It is to be observed that the prolongations between C and H are not drawn, they may be traced in pencil if required.

The degrees are numbered upon the interior arc KT commencing at T, and at the side of each degree is marked the hundredth and thousandth parts of DC, contained between C and the intersection of the prolongation of the radius passing through each degree, with CB.

Commencing at the point N, the extremity of the line DN, which makes with DC half a right angle, the points of intersection of the prolongations of the radii with NC are numbered, with every other one of those upon the interior of the arc GS, that is, the latter being 0, 87, 176, 267, 363, 466, 577, 700, 839, &c., those to be written upon NC will be 0, 176, 363, 577, 839, &c.

These are the numbers upon our plate, but if this is increased to the requisite size for practice, there would be many additional numbers, as ours are for every fifth division of the ark, supposing it divided into degrees, whereas for practice those for every degree will be necessary.

Thus far our figure only gives the ratios, in order to have the true dimensions, trace on each side of the figure six parallel and equal lines to AD; make one of these a scale of 25 yards, and the five others, scales of 20, 15, 10, 5 and 2 yards. For every operation we can assume such a scale as contains a sufficient number of yards for the height of wall to be built, and when a scale has been adopted, it must be adhered to throughout the work.

The divisions of the lines FB and TC show the relation between the specific gravities of earths and masonry from $\frac{60}{100}$ or $\frac{3}{5}$ to $\frac{90}{100}$ or $\frac{9}{10}$, and if a case should occur beyond these limits, which will be very rare, we have only to extend the divisions of FB either in the direction of A or B, and make new divisions on the same scale and in the same manner as those between F and B. We should operate in the same manner for numbers less than 60 or greater than 90, as for those from 60 to 90, and the results applicable from 40 or 50 up to 120 or 130 will possess all the exactness necessary for practice.

This *graphical formula* should be constructed upon a strong, smooth piece of paper, and pasted upon thick pasteboard or wood, in order to render it durable.

The following is the manner of applying this formula to determine the dimensions of walls to support earths of various kinds.

Suppose it is required to construct a wall 13 yards in height, with a slope on one side only, of 8 horizontal parts to 100 vertical, to sustain earth, one cubic yard of which weighs $\frac{77}{100}$ of a cubic yard of masonry, and suppose the earth to have been newly embanked and to take a slope of which the height is $\frac{44}{100}$ of the base.

Take upon the scale of 15 yards, a length Dh, equal to 13 yards; draw lightly with the pencil a line hk parallel to CD, the part of this line $e''f'$ comprehended between De, which corresponds to a slope of 8 upon AE, and Df corresponding to the number 77 upon FB, will be the thickness of the wall at the top; after which draw $f'G$ perpendicular to DC; the trapezium $De''f'G$ will be the transversal profile required.

If it were required to give the wall a slope of $\frac{8}{100}$ upon each side after having drawn the line hk, the thickness of the wall at the top will be $e'''f'$, the point e''' will be upon the line De' corresponding to the number 8 plus $\frac{1}{2}$ of 8, or 12 of the line AE. Through the point e''' draw $e'''d$ parallel to $e''D$, then lay off he'' from G to d', and the trapezium $de'''f'd'$ will be the transversal profile of the wall required.

In general, the posterior extremity f' of the superior line of the profile, is found upon the line Df answering to the ratio of the specific gravities; with respect to the front extremity, if there is but one slope

it is found upon the line of slope drawn from the division of AE; and if there are two equal slopes, it is found upon the line answering to once and a half the slope upon AE, and at the intersections of these same lines of slope with the top line of the wall.

Suppose now that it is required to give the wall two different slopes, the exterior one $\frac{12}{100}$, and the interior one of $\frac{6}{100}$. The posterior extremity of the top line of the profile will always be found in f' upon the line Df corresponding to the ratio $\frac{77}{100}$ of the specific gravities. In order to find the front extremity of this line, take upon hk the *point* e'''' corresponding to the number 12 plus $\frac{1}{2}$ of 6, that is, 15 of the divisions of AE; the thickness at the top will be $e''''f'$; then proceed in the same manner as in the last case.

The above cases are, as we have already said, applicable to many cases of practice, because supposing the wall constructed according to all the rules of masonry, they give dimensions which we may employ with perfect security. If we wish to know now, the reductions in thickness which may be made, resulting from physical considerations of which we have spoken, the following is the mode of proceeding:

Through that division of TC corresponding to the ratio of the specific gravities, draw a parallel to CB; draw another line passing through D and that division of NC, which is marked with the number of thousandth parts of the base of the slope of the earth, contained in the height of the same slope; this is either given or deduced from the angle which the natural line of slope makes with the horizon; these two lines are gQ and DX; in our example, they intersect in Q; lay off gQ from A to q upon AB, and draw the line qD; the point f'' where the line intersects hk will be the interior extremity of the top line of the profile of the wall; the front extremity of this line is determined as before.

If the thickness given by equation (21)* and its derivations, is required, we draw a radius DR from the centre D to the point of division of the quadrant CH corresponding to the inclination of the line of slope with the horizon, or to the division of TK which indicates how many thousandth parts of the base the height of the natural slope of the earth contains; from the intersection x of this radius with the concentric arc drawn through that division of TC representing the ratios of the specific gravities, let fall the perpendicular xr upon DC; and lay off the distance from the foot of this perpendicular to D (that is, in our example, Dr) from A to i upon AB; draw the line iD, and its intersection f'' with hk will give the interior extremity of the top of the profile, the front extremity will always be found as before.

* This equation, as M. de Prony shows in his *Recherches*, conducts to an incomplete and empirical solution; however, the formula which contains this solution may have useful applications; it conducts, when the pressure of water is considered, or earth, which has very little cohesion among its particles, to the same results as our methods above given; but in proportion as the line of slope is more inclined to the horizon, it gives a greater thickness; in general, it is found that this equation and its derivations give a greater thickness than the equations where the friction, cohesion, &c. are considered, and a less thickness where these circumstances are neglected; that is, mean thicknesses, which may be used with security when we are convinced that no circumstances can change the natural slope of the earth beyond what we introduce into our calculation.—Auth.

We have but one word to add to the foregoing, that is, to show how we may apply the *graphical formula* to cases where the superior surface of the soil supports a weight uniformly distributed throughout this surface, as it would be with flag stones, pavement, &c.

These cases possess no additional difficulties, and introduce no change; they only require attention to substitute for the ratio of a to b that of $a + \frac{3G}{h}$ to b.* To elucidate this by an example, which to practical men is a complete explanation, we will suppose that, for a wall, the height of which is to be 10 yards, the earth weighing 1500 pounds per cubic yard and the masonry 1875 pounds, the superior surface is loaded with 312½ pounds per square yard; we shall have, by proceeding as above, find the number of hundredths contained in $\frac{1500}{1875}$ which is .80, then employ on the diagram the number 80 of *FB* or *GC*; but in this case, where each square yard of the surface of the ground supports a weight of 312½ pounds, we must divide the triple of this weight or 937½ pounds by 10, the number of yards in the height of the wall, add the quotient 93.75 to the 1500, and find how many hundredths there are in $\frac{1593.75}{1875.0}$; it will be found that there are 85, we then use the number 85 of *FB* or *TC* as we would before have used the number 80.

We shall say nothing of the case where a parapet is raised upon the wall; the best way to proceed in this case, is to operate first, without considering the parapet, by the methods given above, and afterwards to find the reduction in thickness from the weight of the parapet, the very simple arithmetical calculation is given in *Art.* 32 of *Les Recherches.*†

A short Description of Marine Railways.

A marine railway is an application of the inclined plane and railway to facilitate the repairs of shipping; and is essentially composed of a cradle placed on wheels moving upon rails, which are placed upon an inclined plane.

* a is the specific gravity of earth; b is that of masonry; G is the weight supported by a unit or the surface; h is the height of the wall.—TR.

† The following is the rule alluded to above.

To the total front slope add half the thickness of the parapet; multiply this sum by the area of the transversal section of the parapet; divide this product by another product composed of two factors, of which one is the height of the wall, and the other the thickness of the wall at the base, diminished by half of the total slope of the interior face; the quotient will be the diminution in the thickness sought.

M. de Prony calls the *total slope* of a wall, the height from the bottom of the foundation to the top of the coping, multiplied by the ratio between the base and height of the slope.

This reduction is so small it is frequently not necessary to take it into consideration.—AUTH.

The railway most in use is that called the *Scotch Railway*; the cradle is formed of oak, and consists of three longitudinal pieces of the requisite length, depending upon the size of the vessels to be moved upon it; the middle piece is more than twice the breadth of the other two or side pieces, and is called the *keel piece;* this is connected to the side pieces by a number of cross pieces. Upon the under side of these longitudinal pieces are attached the standards for the wheels to move upon and in. The keel piece has a double row of wheels; these are made of cast iron and are about one foot in diameter, made solid with a spherical segment on each side. The side wheels have a flange on each edge, those on the keel piece have only one on the exterior edge; these move upon cast iron rails, which are formed of a plate with the rail raised in the middle for the sides, and on the exterior edges for the keel; these are spiked or bolted upon timber laid with the necessary inclination upon piles or other solid foundation. The centre rail is a broad plate with a rail on each edge between which there are teeth or catches for the support of the palls, which are attached to the keel piece to support the cradle when drawn up.

The length of the inclined plane depends upon the rise of the tide, for a constant inclination, and upon the size of the vessels to be moved upon it.

The cross pieces, which connect the side and keel together, have a toothed plate upon their superior sides, flush with the surface; upon these pieces the cheeks are placed to support the vessel upright; these are kept upon the cross pieces by plate-catches which fit into grooves made in the sides of the cross pieces. The cheeks are of solid timber and are as thick as the cross pieces are wide; they slide upon the cross pieces and are moved by means of cross pullies passing under the ship's bottom. These are kept from sliding back when once drawn under, by means of tongues placed on the exterior ends which catch in the teeth of the plate.

The cradle is moved by machinery of various combinations, with horse power. Generally by means of an endless toggle-jointed chain, so arranged as to geer with the cogs on the axle of the moving wheel. To this is attached an iron dog, to which the moving chain is fastened.

To draw a vessel up, the cradle is let down to the lower end of the plane, and at high water the vessel is floated over it. As soon as the tide falls, she will ground upon the keel piece, and the supporting cheeks are drawn under her bottom; when the machinery is put in motion and she is drawn out of water; the vessel may then be examined and repaired with great expedition and facility.

The best inclination for a marine railway may be found by the rule given in the *note* at the end of our work.—Tr.

Demonstration of the Rule given at p. 196.

Let there be a descending trade, of which the weight including the carriages, is W; and an ascending trade, of which the weight, including the carriages, is $n\,W$. Let $R =$ the radius of the wheels, and $r =$ the

radius of the axles, f = the friction when the pressure is unity. Suppose that the power acts parallel to the rails on which the wheels move, and let P = the moving power, F = the resistance from friction at the axle. Then $P - F$ = the part of the power employed in causing the carriage to ascend, and $W S$ in inclination $= P - F$; but F is proportional to the pressure on the axis which is W; hence $F = \frac{W f r}{R}$; consequently, $W\left(\sin i + \frac{f r}{R}\right) = P$ = the power to move the carriage up the plane. And $W\left(\sin i - \frac{f r}{R}\right)$ = the tendency of the carriage to descend; then, in order that the trade may be conducted in either direction by the same power, we must have

$$W\left(\frac{f r}{R} - \sin i\right) = n\, W\left(\frac{f r}{R} + \sin i\right);$$

or,

$$\frac{f r}{R} - \sin i = \frac{n f r}{R} + n \sin i;$$

whence,

$$\sin i = \frac{f r (1 - n)}{R(1 + n)}.$$

If the wagons are not to be returned, then $n = 0$, and we have

$$\sin i = \frac{f r}{R}.$$

And when $n = 1$, or the trade is equal in both directions, $\sin i = 0$, as it should be, indicating that the road should be level.—*Tredgold on Railroads*, *p.* 59.

DESCRIPTION OF THE PLATES.

PLATE I.

Fig. 1, is fully explained in the body of the work at page 79.

Fig. 2, shows the profile of a paved causeway and the thickness of the different layers composing it.

Fig. 3, shows the profile of a paved road where the sides or wings are inclined towards the causeway.

Fig. 4, is a finished profile of a road on level ground with a paved causeway.

Fig. 5, the profile of a causeway in gravel or stone.

Fig. 6, the same as *Fig.* 4, except the causeway is gravelled, or covered with broken stone.

Fig. 7, is the profile *à revers* for mountain roads.

Fig. 8, is the profile of a road for high ground, as the side of a hill, together with the drain for the water.

Fig. 9, is a profile for the same construction of the road.

Fig. 10, is a series of simple levels. A man with a levelling staff is placed at *A* and *B*, the position of the instrument is shown on the figure together with the line of sight, the heights at *A* and *B*, as *A a*, *B b*, are marked. The same is repeated for *B* and *C*, &c.

Fig. 11, shows the same simple levels recorded, or referred to the same line, and the manner of writing the references, the numbers between the ordinates show the quantity of rise or fall, + indicat- fall, and — rise.

Fig. 12, are cross levels.

Fig. 13, is a diagram for the problem referred to in a note in the body of the work.

Fig. 14, explains itself.

PLATE II.

Figs. 15, 16, 17, 18, 19, 20, 21, 22, are sufficiently explained in the body of the work.

Fig. 23, shows the manner of joining the voussoirs to the head stones of an arch; *a*, *a*, show the elbow voussoirs.

Fig. 24, is a flat arch, and shows the manner of carrying up the pier in order to prevent the meeting of three edges at the spring of the arch.

Fig. 25, shows a method of joining the voussoirs to the horizontal courses, which is much practised.

Figs. 26, 27, 28, 29, 30, are clearly explained at their proper places in the body of the "Course."

PLATE III.

Fig. 31, is a diagram illustrative of a problem in the body of the work.

Fig. 32, represents a vertical and horizontal projection, together with a side projection of a *wing wall* for a culvert. *A* is the vertical projection, *B* the horizontal, and *C* the side projections; *a*, *b*, shows the side projection of the elbow given to the stones of the wing wall to prevent their sliding, and the manner of drawing it.

PLATE IV.

Fig. 33, shows a centre for a large stone bridge of the most approved construction.

Fig. 34, is a diagram for the problem *to find the centre of cutting.*

Fig. 35, represents the draught for a wing wall.

Suppose *Y* to be the head of the bridge or culvert, *X* a lateral vertical section across the bridge at *B*, or the centre. *AD* is the height of the socle, *D h* the intersection of the vertical cutting plane with the superior surface of this socle. From the top of the road way *D′* draw a line *D′ C* making with the ground such an angle as it is required to give the exterior surface of the wall, in this case, 45°, and at any convenient distance from the extremity of the socle, as *d e*, raise the perpendicular *d c* of a convenient length, which will be the extremity of the dye, and draw the line *b c* with a slight inclination, and *b c d* will be the lateral projection of the dye.

To obtain the horizontal projection of the wing wall, project the point *P* in *o*, and draw the line *o h′* making an angle of $22\frac{1}{2}°$ with the stream, and this line will be the intersection of the interior plane of the wall with the top plane of the socle. Draw the line *S′ S″* parallel to *o h′* which will be intersection of the interior plane of the socle with the ground, the point *e* projected into the line *S′ S″* will be the horizontal projection of the extremity of the socle; lay off on the line *S″ S‴* the thickness to be given the wall. Project the point *d* down and draw the line *n r*. To find the intersection of the superior plane of the wing wall with the interior surface of the same. We know that the intersection of their horizontal traces, the point *d′*, will be one point in it; to find another, make the point *P* or *o* the vertex of a cone, whose axis shall be equal to the height of the wall *DD′*; the base of this cone *g y m* is in a horizontal plane passing through the line *SB*, and its radius is equal to the inclination to be given to the interior surface of the wall, in this case $\frac{1}{8}$; through the line *h′ o* pass a tangent plane to this cone; the trace of this plane on the horizontal plane passing through *SB* will be *f p*, parallel to *h′ o;* the intersection of this *horizontal* trace with the trace *OA* will be a point in the intersection sought; then draw *d′ O* which will be the line wanted. Project the point *b* in *b′* and draw *b′ n′* parallel to *s″ s‴*, and draw *h′ b′* through *h′* and *b′*, and we have the horizontal projection of the dye. By means of the horizontal and

lateral projections found, it is very easy to find the vertical projection. The line $b' R$ is projected vertically in $b'' R'$, $i\ b''$ in $i'\ b''$, $b'\ h'$ in $b''\ h''$, the line $n'\ b'$ is projected in $n'''\ b''$, and thus for the whole; $h''\ d''$ represents the earth, $d''\ o$ its slope.

PLATE V.

Fig. 36, is the plan and section of a canal lock with two gates. On the plan the side *X* is supposed to be finished, while the side *Y* shows the wall unfinished; *a* is the groove for stop planks at the head gate, *b* the entrance into the paddle *b′* the opening of the same into the chamber, *c* the balance beam and gate, *r* the mitre-sill, *d* the lock fall, *s* the hollow quoins; *g* shows the mitre-sill with the gate open, *p* is the sliding gate for letting the water out of the lock, *k* shows the manner of laying the grillage at the tail platform, and the spaces between the piles, which are filled with rubble stone mortar or clay, *h* is a part of this platform completed.

Fig. 37, is a section of the lock below the fall.

Figs. 38 and 39, represent an elevation and section of an edge rail road, showing a rail at *a* connected with two adjoining rails, and also with the props on which they rest; *d* shows the metal chairs, *f f* the stone sleepers; the joints *e e* are made by applying the ends of the rails to each other by a half lap, *g* the pin passing through them, which fixes them together and to the chair in which they are inserted, which should exactly fit the hole drilled through the chairs and ends of the rails, which should be at such a height as to allow both ends of the rails to bear on the chair, the bearance being the apex of a curve, they will both bear at the same point. Thus the end of one rail cannot rise above that of the adjoining one; for although the chair may move on the pier in the direction of the line of the road, yet the rails will still rest upon the curved surface of their bearance without moving.

Fig. 40, represents the elevation of a tram wheel and a section of the rail and chair, showing the mode of fastening the chairs to the sleepers.

PLATE VI.

Fig. 41, is the diagram to a Note at the end of the work, for the pressure of earths, &c.

Fig. 42, represents the plan and section of the river end of a tide lock, the bottom of the lock being an inverted arch laid upon a log foundation placed on piles. The gates are cast iron framed, moved by means of capstans and chains. This plate is copied from *Mr. Strickland's Reports*, and is a representation of the Frindsbury lock on the Thames and Medway canal; it is built of brick coped with stone.

Fig. 43, represents a top view and elevations of cast iron sheeting piles, which are used in England for forming coffer dams; they are found to be much more economical, both in first cost and the expedition with which they are placed and removed, more particularly when the depth of water is not very great.

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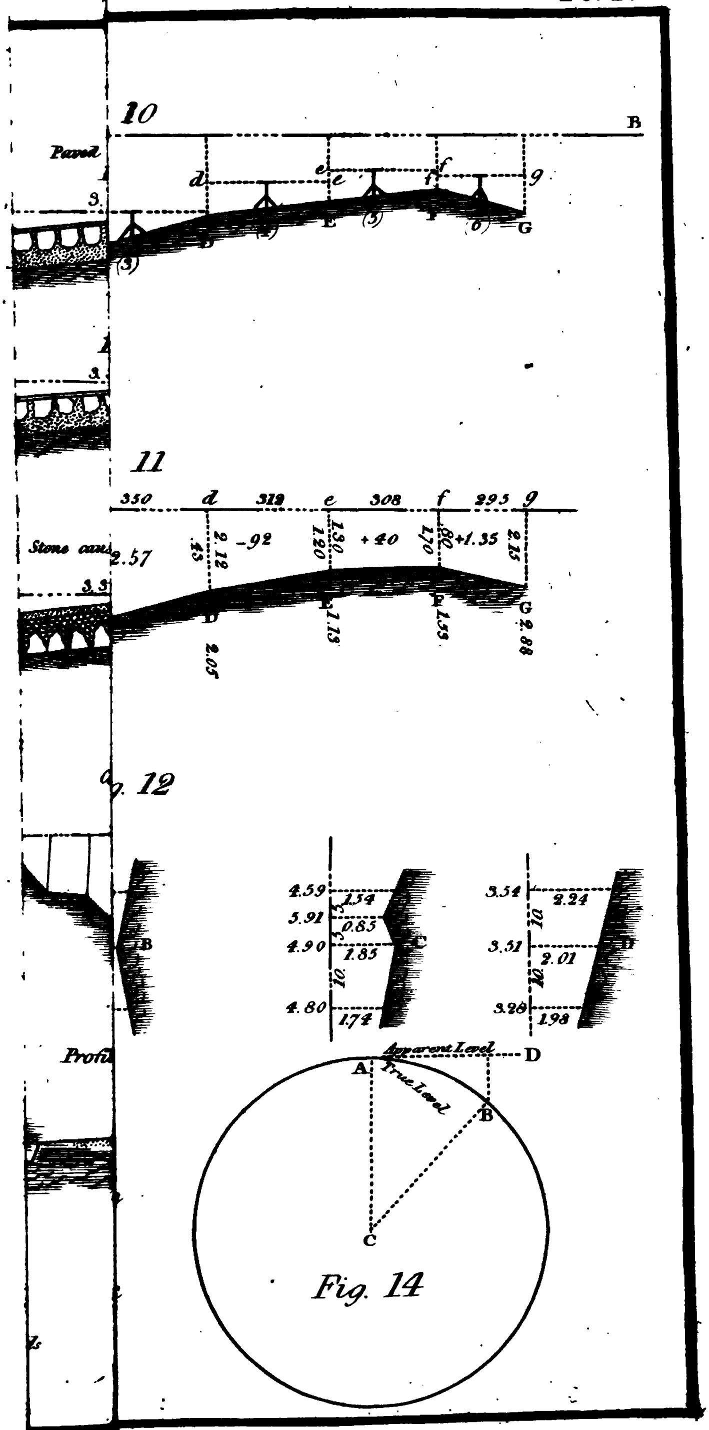
Pl. I.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1.74
3.54
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Profil
Apparent Level
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Fig. 14

Pl. II.

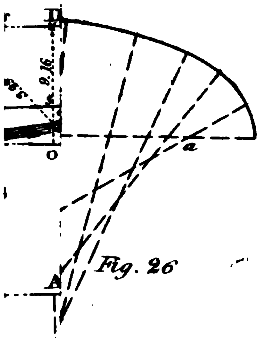


Fig. 26

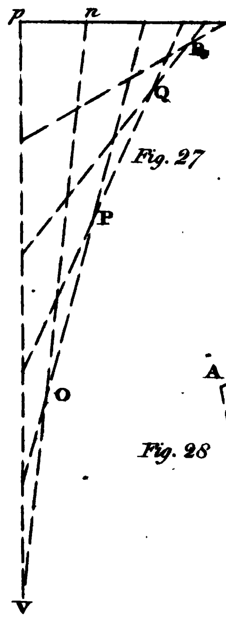


Fig. 27

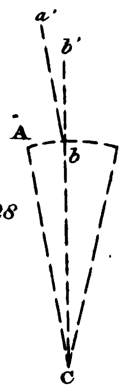


Fig. 28

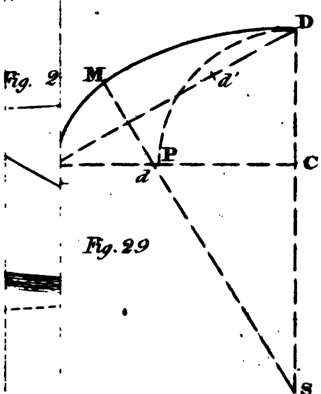


Fig. 29

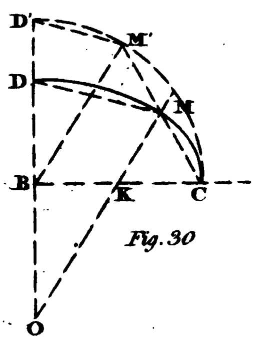
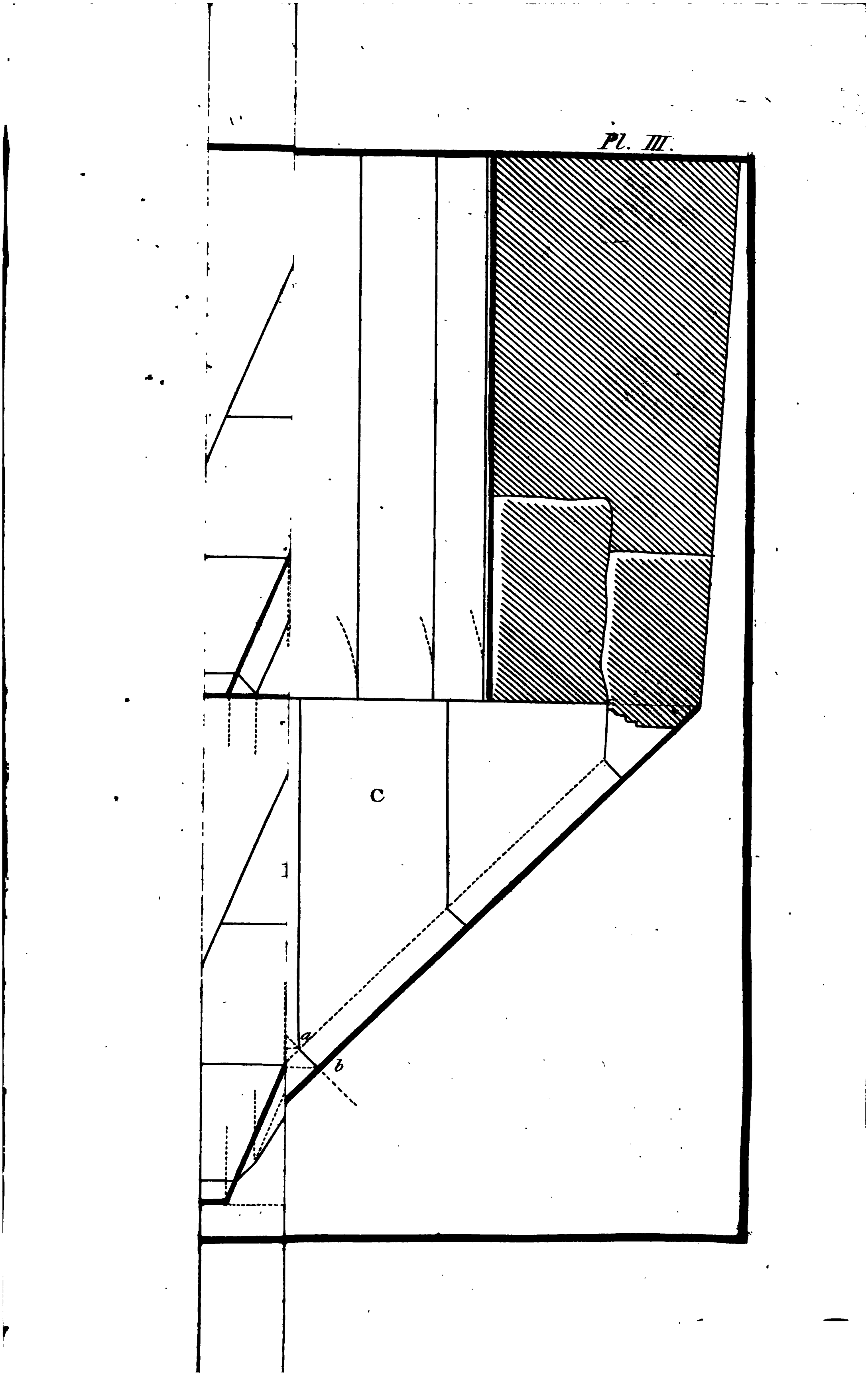


Fig. 30

Pl. III.



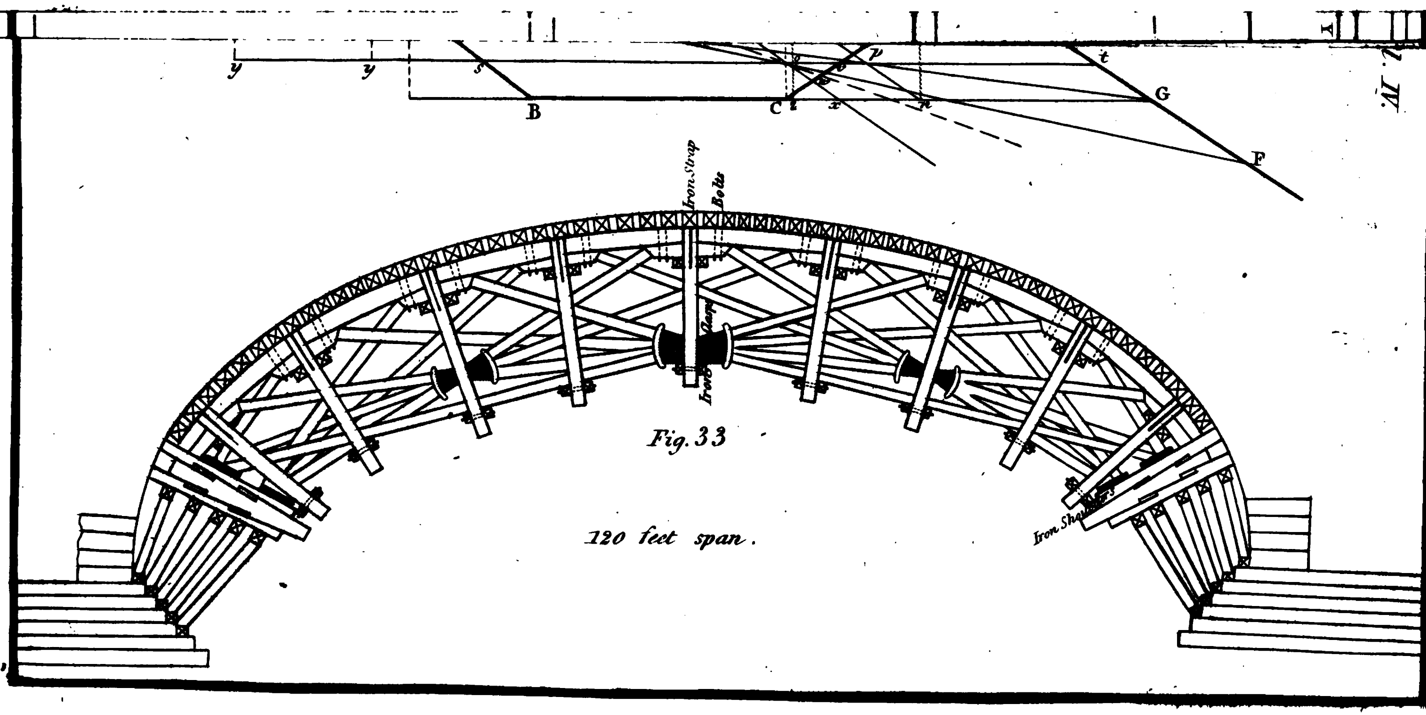
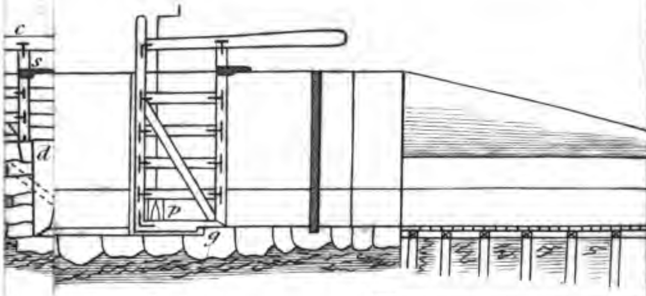
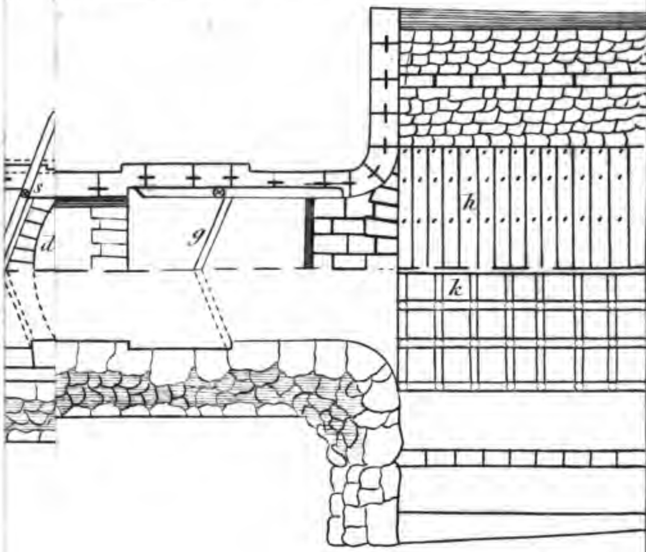


Fig. 33

120 feet span.

Plate V.





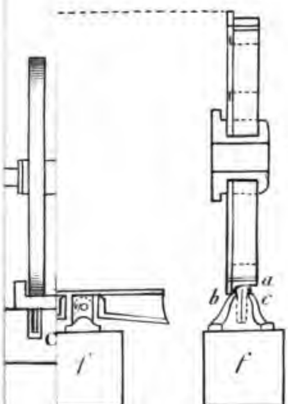


Fig.39

Cast Iron, Sheeting Piles.

Modeof putting them togather.

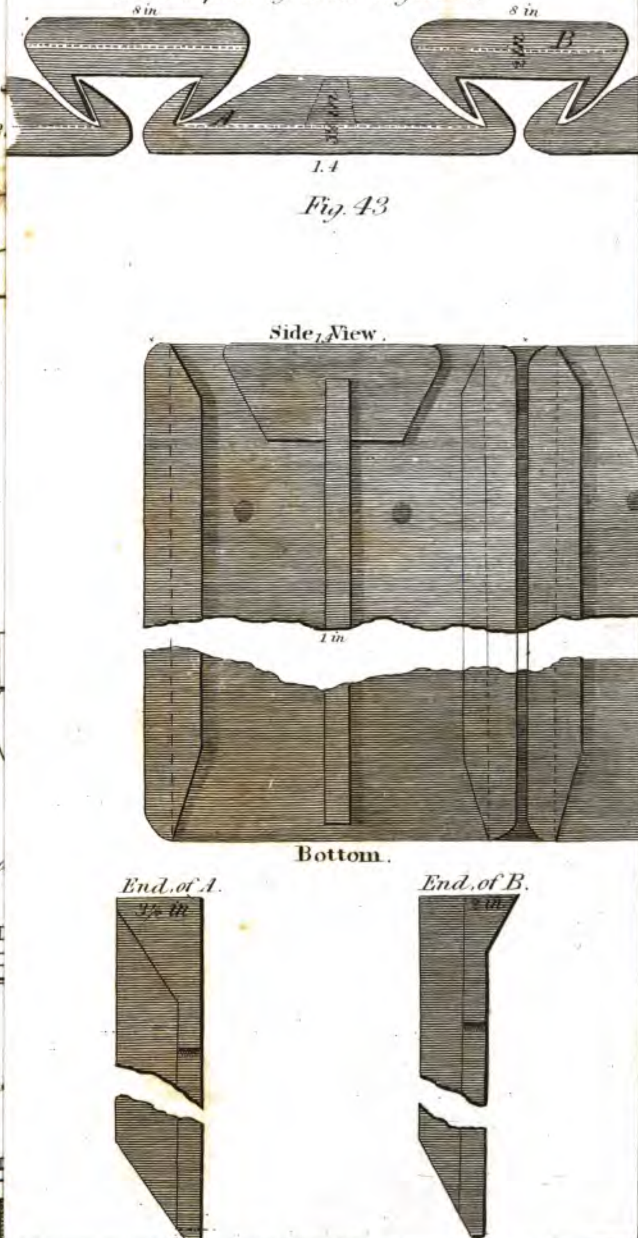


Fig. 43